Eesti Maaülikool
Estonian University of Life Sciences

ROLE OF HISTORICAL SLASH AND BURN CULTIVATION IN THE DEVELOPMENT OF CULTURAL LANDSCAPES AND FOREST VEGETATION IN SOUTH ESTONIA

AJALOOLISE ALEPÕLLUNDUSE ROLL LÕUNA-EESTI MAASTIKE JA METSATAIMESTIKU KUJUNEMISEL

PILLE TOMSON

A Thesis
for applying for the degree of Doctor of Philosophy
in Environmental protection

Väitekiri
filosoofiadoktori kraadi taotlemiseks keskkonnakaitse erialal

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CONTENTS

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This thesis is based on the following papers, which are referred in text by their Roman numerals

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II: **Tomson, P.**, Bunce, R.G.H., Sepp, K. (2016). Historical Development of Forest Patterns in Former Slash and Burn Sites in Southern Estonia. In: Angoletti, M., Emanueli, F. (Eds.). Biocultural Diversity in Europe (303−318). Switzerland: Springer. (Environmental History; 5).10.1007/978-3-319-26315-1_16.

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IV: **Tomson, P.**, Kaart, T., Sepp, K. Macroscopic charcoal in forest soils in the context of slash and burn cultivation and forest fires. Silva Fennica. Submitted (2018).

The contribution of the authors to the papers:

	I	II	III	IV
Original idea	PT	PT	PT	PT
Study design	PT	PT	PT, RGHB	PT
Data collection	PT	PT	PT, RGHB	PT
Data analyses	PT	PT	TK, PT	TK, PT
Manuscript preparation	PT, RGHB, KS	PT, RGHB, KS	PT, KS, TK	PT, KS, TK

KS–Prof. Kalev Sepp
PT–Pille Tomson
RGHB–Prof. Robert Gerald Henry Bunce
TK–Tanel Kaart

ABBREVIATIONS

AMS	accelerator mass spectrometry radiocarbon dating
ANOVA	permutation analysis of variance
calAD	calibrated radiocarbon date Anno Domini
calBC	calibrated radiocarbon date Before Christ
con	conventional radiocarbon dating
EAA	reference code of the National Archives of Estonia
FMD	Forest Management Database
LPA	landscape protection area
NP	national park
NaP	nature park
NPA	nature protection area
PCA	principal component analysis
PC	principal component
perMANOVA	permutational multivariate ANOVA

1. INTRODUCTION

Traditional land uses have formed specific mosaic landscapes. Heterogenous practices of extensive agriculture have created various semi-natural habitats that are rich in biodiversity. Land use changes during the 20th century have affected landscapes and biotopes all over Europe. Agricultural intensification has been accompanied with the abandonment of non-productive and remote agricultural land, followed by afforestation.

Semi-natural habitats that have been formed due to the mowing and grazing of livestock are well known and valued because of their specific biodiversity and their position in traditional landscapes. In contrast with these land use practices, little attention has been paid to the effects of slash and burn cultivation in Europe.

Slash and burn cultivation in Europe persisted up until the Modern Era. In the first half of the 20th century, slash and burn cultivation was still practiced in Germany, Austria, Finland, Sweden, Russia, Latvia, and Estonia (Sigaut, 1979; Hamilton, 1997; Bobrovsky, 2010; Jääts et al., 2010). Different terms have been used to describe the use of fire to prepare land for agricultural use: slash and burn cultivation, swidden agriculture, and even burn-beating in older scientific literature (Soininen, 1959; Weimarck, 1968). In the present study, slash and burn cultivation and swidden cultivation are used as synonyms. Numerous older 20th century publications are available only in Finnish, Russian, or Swedish. The 18th–19th agricultural guidelines and reports in Estonia were written in the Baltic German dialect. These language problems have complicated the studies of slash and burn cultivation.

The legacies of slash and burn cultivation in landscape, such as the *aho* (a specific kind of grassland) and the deciduous wooded pastures that have formed in abandoned slash and burn fields, have been studied and valued in Finland (Eriksson, 2008). The modern slash and burn cultivation is applied to restore these habitats in protected areas (Lovén and Äänismaa, 2006). However, in Estonia, the utilisation of slash and burn cultivation has mainly been described by historians.

In Estonia, slash and burn cultivation was more widespread in the southern regions of the country. A system of rotational slash and burn cultivation in young forests with a cycle of about 20–25 years was developed by the 19th century. A special land category, *buschland*, was used for areas that were regularly utilised for slash and burn cultivation (Ligi, 1963).

The 19th century was a period of decline in slash and burn cultivation in Estonia. The subsequent abandonment of *buschlands* has been paid little attention. Some authors have offered brief speculations on the effects of slash and burn cultivation on forest composition, among other issues (Laasimer, 1965; Rõuk, 1995; Paal 1997). Meikar and Uri (2000) discussed the management of shrubby areas in Estonia using historical records and books, and also addressed the issue of *buschland*s. Raet et al (2008) assessed the changes in forest coverage on the basis of historical maps and described the *buschland*s as a 'grey' zone because there is no relevant equivalent in modern land cover. There have not been any studies undertaken in Estonia on the effects of historical slash and burn cultivation *in situ*.

Knowledge of landscape history is essential to ensure that valid decisions are made during planning processes (Marucci, 2000; Antrop, 2005). The present status and value of former slash and burn areas in protected areas is rarely discussed in the scientific literature in countries other than Finland. There is little information to help determine whether the former land cover in former slash and burn areas should be restored and managed in the same way as other anthropogenic habitats, or whether the recovering wilderness should be protected in these areas.

Considering the historical extent of slash and burn cultivation in northern Europe, a more thorough analysis of the characteristic features of former slash and burn cultivation lands, their extent, and how they have changed is needed to understand the role of former *buschlands* in the formation of the modern landscape. For the proper management of former slash and burn areas, it is essential to examine their vegetation. However, slash and burn cultivation has produced and deposited black carbon into the soil. Soil charcoal in boreal forests has become a topical issue due to the global carbon cycle and climate change, but the interpretation of these charcoal deposits has yet to be unravelled (Halshall et al., 2018)

This dissertation is focused on the effects of rotational slash and burn cultivation on the cultural landscapes and forest vegetation in the former *buschland*s. The former land uses of the observed sites were identified using 19th century maps. The maps used were produced in the second half of the 19th century. There is no available information, however, as to the proportion of *buschland*s that were used for slash and burn cultivation, and how many had already been converted into new arable land or used as pasture at the time the maps were drawn. It is most likely that in some cases the earlier maps were used as a basis to draw the updated versions. For example, it is noted on the 1862 map of Mähkli farm that this is an adapted copy of an earlier 1801 map. The date of slash and burn cultivation in the study areas was not recorded. The correspondence stored at the Estonian National Museum, recorded in the 1940s, notes the end of slash and burn cultivation in surrounding areas until 1895, and use of burn-beating until 1910 (Jääts et al., 2010). Therefore, the term '19th century land use' is used in the present study without a more precise definition of the exact time period.

The study consisted of three stages, each of which was based on the previous stage:

1. A map analysis of characteristics of historical slash and burn land, and changes in land use of slash and burn cultivation patches (I; II);
2. A vegetation survey to analyse vegetation differences in former slash and burn cultivation sites and forests, including soil sampling (III, IV);
3. Additional surveys to examine the soil charcoal deposits, and to explore methods to identify areas used for slash and burn cultivation agriculture (IV).

Robert Gerald Henry Bunce supervised the preparation of the first two manuscripts, and Kalev Sepp supervised the latter two papers.

2. REVIEW OF LITERATURE

2.1. Slash and burn cultivation in Europe

Slash and burn cultivation in central Europe was viable up until the 19th century (Sigaut, 1979). In the eastern regions of Finland–such as Karelia and Savo–slash and burn cultivation was even still being practised in the 1930s (Voionmaa, 1987), and was still practiced in north-western Russia until the 1960s (Bobrovskii, 2010). By the 20th century, up to 75% of the forests had been used for slash and burn cultivation in some regions of eastern Finland (Heikinheimo, 1915). In southern Finland, slash and burn cultivation lost importance as an independent cultivation method during the medieval period, but in eastern and northern Finland swidden agriculture was vital up until the 20th century (Sarmela, 1987). At the same time, the importance of the forest economy increased, and therefore slash and burn cultivation was restricted (Goldhammer and Bruce, 2004). Rotational slash and burn was common in the southern part of Sweden up to the end of the 19th century (Weimarck, 1968; Hamilton, 1997). In the western part of Värmland and Dalecarlia, the 'Forest Finns' used mature forests for slash and burn cultivation, but in 19th century young forests were generally used for this practice (Hamilton, 1997).

2.2. Slash and burn cultivation in Estonia

In Estonia, different authors (Ligi, 1963; Meikar and Uri, 2000; Tarkiainen, 2014) have described slash and burn cultivation in both mature forests and young forests, as was observed in Finland. Slash and burn cultivation in mature forests has been considered to be the earlier method, and the regular burning of young forest to be a later development as land shortages in Estonia caused the shortening of the burning cycle. Pollen analysis has suggested that the interval between burnings was approximately 180 years in the Haanja upland during the Bronze Age (Laul and Kihno, 1999). Slash and burn in old-growth forests that was not followed by land clearance for arable use was prohibited by the state in the 17th century (Etverk, 1974). In northern and western parts of Estonia, the importance of slash and burn agriculture decreased during the Middle Ages and was used instead to prepare new arable land. At the same time, slash and burn cultivation was still an individual method of crop cultivation in southern Estonia until the 19th century (Ligi, 1963). Tarkiainen (2014) has hypothesised that mature forest slash and burn cultivation may have been introduced in the 17th century by Finnish immigrants, as it had been in Sweden and Norway. During the 19th century, the cycle of rotational slash and burn cultivation lasted about 20–25 years (Meikar and Uri, 2000; Jääts et al., 2010). Rotational slash and burn cultivation was designated as the special land category *buschland* in the Baltic Germany dialect.

Every year, some patches of *buschland* were slashed, left to dry, burned, and cultivated for a few years. The abandoned fields were used for grazing until the new generation of trees recolonised the land, and it slowly became ready for the next cycle of slash and burn to begin after 20-25 years (I). The dominant tree species in *buschland*s were silver birch (*Betula pendula* Roth), grey alder (*Alnus incana* (L.) Moench), and Norway spruce (*Picea abies* (L.) H.Karst.) (Ligi, 1963). Agrarian law in 1850 allowed for *buschland* to be converted into permanent arable land; the remaining *buschland*s had to be divided into 24 sections, only one part (about 1 ha) of which was permitted to be burnt and cultivated for three years (Liiwlandima Tallorahwa Säeduse-ramat, 1850).

The 19th century was a declining period for rotational slash and burn cultivation. The land revision in 1881/83 (Livländisches Landraths-Collegium, 1885) recorded that, in the Võru district, 11.3 % of land belonging to private manors were covered by *buschland*s. In Karula parish, *buschlands* covered 5.4 % of such land, and in Rõuge parish (in Haanja Upland), this was 10.5 %. *Buschland*s were more widespread in lands utilised by peasants: 15.4 % in Karula parish, and 27.8 % in Rõuge parish. In land used by landlords' households, the proportion of *buschlands* were considerable lower: 4.8 % in Rõuge parish, and only 1.0 % in Karula parish (Livländisches Landraths-Collegium, 1885). During the 20th century, slash and burn was used mainly for land clearing.

2.3. Research status

In 1979, French anthropologist François Sigaut expressed astonishment at how European anthropologists had completely ignored European slash and burn cultivation, which had been practiced in Germany and Austria up until a few decades prior to the publication of his paper

(Sigaut, 1979). Almost the same can be said about the environmental sciences.

In 1915, when slash and burn cultivation was still widely used in a large part of Finland, a thorough overview of the effects of slash and burn cultivation in Finnish forests, consisting of descriptions of tillage methods, yields, and forest regeneration, was published (Heikinheimo, 1915). This book remains an important source of information today.

In Estonia, slash and burn cultivation has gained little scientific attention. The most cited reference on the topic is a chapter in the book *Agricultural land use in Estonia in XVI–XVII century* (*Põllumajanduslik maakasutus Eestis XVI–XVII sajandil*) by Ligi (1963) that is devoted to slash and burn cultivation. Meikar and Uri (2000) published a paper on the management of shrubby areas, which also considered land used for regular slash and burn cultivation. Historian Tarkiainen (2014) published an overview of slash and burn cultivation as a landscape design and cultural factor, describing both Estonian and Finnish practices. Tarkiainen (2014) completed the report on the techniques and spread of swidden cultivation using records of land revisions, historical maps and map descriptions, and historical handbooks from the 17th and 18th century. These studies were not associated with locations in modern landscape.

The fate of *buschlands* after the decline of slash and burn cultivation has received little scholarly attention in Estonia. Liitoja-Tarkiainen (2006) considered *buschlands* in the 19th century as grasslands, Meikar and Uri (2000) saw them as forest. Raet et al (2008) used map analysis to demonstrate that approximately half of the *buschlands* mapped in the 19th century were afforested in the mid-20th century.

2.4. Characteristics of slash and burn cultivation

Slash and burn cultivation was associated with extensive land use, and the areas used for slash and burn cultivation were not closely related with villages or households as permanent arable fields. In Sweden, the swiddens were located in the outlands (Berglund et al., 2014), i.e. in the external zone of village lands.

Usually the *buschlands* were located at a distance from households, while the permanent arable lands, which were manured with dung, were closer

(Ligi, 1963; Liitoja-Tarkiainen, 2006). Numerous authors have emphasised that slash and burn cultivation was associated with hillsides. Tarkiainen (2014), referencing the handbook written by Gubert (1688) *Stratagema oeconomicum*, stated that slash and burn must be practised on slopes with good sun exposure to ensure the drying of slashed timbers. An analysis by Koppel (2005) suggested that slopes of 3–4° were preferred for slash and burn cultivation parcels. In Finland, slash and burn cultivation was associated with hilly land in eastern and northern Finland (Sarmela, 1987). Moraine soils are also mentioned as being common in slash and burn areas across northern Europe (Soininen, 1959; Weimarck, 1968). Sigaut (1979) stressed that European slash and burn areas typically were located in mountainous regions and had acidic soils. Soininen (1959) and Weimarck (1968) referred to this as 'rocky land'.

Myllyntaus et al (2002) stressed the role of slash and burn cultivation in the formation of heterogenous landscapes, creating a patchwork of meadows and pastures, deciduous and mixed forests.

2.5. Forest fires

Numerous studies have shown that secondary forests on former agricultural land have different vegetation than ancient forests (Wulf, 1997; Hermy et al., 1999; Dupouey et al., 2002; Verheyen et al., 2003; Wulff, 2003; Wulff, 2004; Hermy and Verheyen, 2007; Matuszkiewicz et al., 2013 etc). The distinctive feature of slash and burn cultivation is the use of fire. Fire has also been a natural disturbance factor in Nordic dry forests (Zakrisśon, 1977; Östlund, et al., 1997; Gromtsev 2002; Anglestam and Kuuluvainen, 2004; Kuuluvainen and Aakala, 2011; Wallenius, 2011 etc). Natural burning occurred in boreal forests before the intensive human fire suppression started (Zariksson, 1977). In addition to natural fires, human-ignited fires, including accidental wildfires caused by the unintended spread of slash and burn cultivation fires, were frequent (Heikinheimo, 1915; Lehtonen and Huttunen, 1997; Lehtonen, 1998; Granstörm, 2001). Therefore, the authors sometimes do not distinguish between natural and human-ignited fires, including slash and burn cultivation (Zarkrisson, 1977).

The burning process and fire intensity are determined by local conditions: weather, vegetation, soil properties, and topography. The effect of prescribed burnings can be more severe than that of forest fires (Viro, 1974), as humans can choose the weather and places for prescribed burnings. Natural burnings are usually uneven and patchy (Vanha-Majamaa et al., 2007). Slash and burn cultivation required evenly burnt areas. Usually, forest fires are primarily surface fires. In case of slash and burn, the effects of fire must be more intensive, because the tree layer has been cut and dried, and the burning processes are controlled and directed to be comprehensive.

2.6. The impacts of fire and slash and burn cultivation on the soil

The information available on soils suitable for slash and burn cultivation is inconsistent. Ligi (1963) described *buschlands* as having thinner and less fertile soils. In contrast, Koppel (2005) suggested that for slash and burn cultivation, humus rich soils were chosen.

There are few studies on the impacts of slash and burn cultivation on soils in the boreal region, but effects of the fire are likely to be similar to intense wildfires. Fire can change the soil by a number of different mechanisms: physical, chemical, and biological (Pyne et al., 1996). Viro (1974) has shown that fires over a 20-year period caused thinning of the humus layer. Fires also change the soil structure. Forest fires could cause soil erosion on slopes (Pyne et al., 1996).

One chemical transformation that is well known is the change in soil pH: just after burning, soil pH rises (Kivekäs, 1939; Viro, 1974; Pyne et al., 1996; Delgado-Matas, 2004; Vanha-Majamaa, 2007). Viro (1974) described an increase of pH 2–3 units in the humus layer. The contents of potassium, calcium, and magnesium in the soil initially rise after a fire then decline slowly, returning to their original levels after 50 years (Viro, 1974). It is not well-known exactly how long-lasting the changes in soils are. Delgado-Matas (2004) studied the impacts of slash and burn cultivation on the soil in Finland, including sites used for cultivation more than 130 years ago, and found the pH and content of chemical compounds to be slightly different in old swidden cultivation sites when compared with soils that had never been burned. Nonetheless, it is difficult to estimate these results; differences in the soil calcium content of sample plots located in different sites were explained as being the result of different parent rocks. Čugunovs et al (2017) compared the soils in former slash and burn cultivation and forest sites using 19th

century land-use maps and found that soil organic layer was thinner in slash and burn sites.

Some authors suggest that slash and burn cultivation promotes soil leaching (Delgado-Matas, 2004; Reintam and Moora, 1983). In Estonia, it is assumed that repeated slash and burn cultivation causes soil degradation (Paal, 1997), and increases podsolisation (Reintam and Moora, 1983). In contrast, Ligi (1963) argued that repeated slash and burn cultivation inhibited podsolisation. Heikinheimo (1915) concluded that "Due to hundreds of years of slash and burn cultivation, what were originally soils of the better forest site types have become similar to those of poorer forest site types, this makes it difficult to say, without closer study of the changes in the development of ground vegetation, as well as in the chemical and physical properties of soil, how long-term and advanced these changes are".

2.7. Effects of fire and slash and burn cultivation on vegetation

Fire can affect ground layer vegetation in several different ways: by destroying vegetation, by creating open ground favourable for the germination of new species, by opening the canopy and increasing light that reaches the ground, and by changing the soil properties. The succession and recovery of the original vegetation after burning can be fast, and several species typical to early successional stages after fire are common.

Numerous studies describe the effects of fire on the forest tree layer composition. Typical post-fire succession pioneer species include pine and birch (Viro, 1974), also alder and aspen (Parviainen, 1996; Hekkala et al., 2004). Some authors report deciduous trees without specifying the species (Axelson and Östlund 2001, Hellberg et al., 2009).

The first vascular plants to colonise burnt areas are rapid-spreading pioneer species (Ruokalainen and Salo, 2006). Plants that are heat tolerant or that have deep rhizomes or fireproof seeds can survive a fire and regenerate afterwards (Schimmel and Granström, 1996; Ruokalainen and Salo, 2009; Hekkala et al., 2014). In the case of natural fires, unburnt islands can remain inside the burnt area and serve as 'spreading centres' (Viro, 1974). Consequently, both regeneration and colonisation take place after fire (Schimmel and Granstrom, 1996).

The possible effect of slash and burn cultivation on forest vegetation has mostly been described at the landscape level. Numerous authors have noted the increase in birch and alder in former slash and burn fields, as is also seen after natural fires (Heikinheimo, 1915; Linkola, 1987; Sarmela, 1987; Vasari, 1992; Parviainen, 1996; Lehtonen, 1998; Hokkanen, 2006). Heikinheimo (1915) also noted the presence of pines. Uotila et al. (2002) concluded that slash and burn cultivation during the 19th century and earlier had changed the tree species and age composition. In Finland, evidence of former slash and burn management has been found in old-growth mesic spruce forests (Uotila et al., 2002). Comparing former slash and burn lands and forests, Čugunovs et al (2017) found that birch was more common in old slash and burn field. In Sweden, the increase of spruce after the cessation of slash and burn cultivation has been noted, as result of grazing in abandoned swidden areas (Lindbladh et al., 2014; Olden et al., 2016). Myllyntaus et al (2002) stated that slash and burn cultivation has promoted ground vegetation species as *Fragaria vesca* L., *Dianthus deltoides* L., *Centaurea jacea* L., *Leucanthemum vulgare* Lam., *Rubus saxatilis* L., *Rubus arcticus* L., *Campanula rotundifolia* L., *Geranium bohemicum* L., and *Oxalis acetosella* L.

Hokkanen (2006) described the forest vegetation in the Koli area, where former slash and burn sites are common. Hokkanen recorded anthropogenic herb rich forests created by slash and burn cultivation and drainage. On slash and burn sites species were found that required more fertile soil conditions, even in cases where the soil pH had decreased back to the initial level. Unfortunately, all recorded human impacts in this study were incorporated into a single factor named 'management', and the impacts of individual management practices were not separable (Hokkanen, 2006). Myllyntaus and Mattila (2002) emphasised that there has not been any agreement in Finland as to whether slash and burn cultivation has caused any permanent changes in forest characteristics.

In Estonia, the prevailing opinion is that slash and burn cultivation has caused vegetation impoverishment. Laasimer (1958) described the formation of dry oligotrophic pine forests and *Oxalis* spruce forests arising from soil depleted by regular slash and burn cultivation followed by permanent cultivation. Laasimer's opinion was based on changes in the trees' pollen abundance approximately 1000 years ago. Later Estonian authors have stated that species-poor spruce forests could grow on former slash and burn sites (Rõuk, 1995; Paal, 1997). Paal et al (2011) examined the species composition of hillock forests in different locations at the beginning of the 20th century using a Russian topographic 'one-verst' map (1:42,000) and the multi-response permutation procedure. The authors suggested that the differences in vegetation revealed were the results of slash and burn cultivation, but did not provide any evidence that large portions of these sites had previously been used for slash and burn cultivation and this practice had transformed the soil properties.

2.8. Identification of slash and burn areas

Difficulties in identifying the exact locations where slash and burn cultivation has been utilised may be the reason why the effect of this widespread cultivation practice has not been widely examined. Some authors have mentioned that swidden agriculture had been present in study areas but did not describe its effects (Uotila and Kouki, 2005; Eriksson et al., 2010).

Koppel (2005) compared historical maps from the 17th and 19th century with modern databases to compute the characteristics of historical land use units, including *buschlands*, and analysed the transitions. Tollin (2017) suggested the use of 18th century large scale geometrical maps in ecological studies. Čugunovs et al (2017) carried out comparisons of selected soil characteristics and woody vegetation between sites utilised for slash and burn cultivation and those not so utilised, using large scale 19th century land use maps. Uotila et al (2002) used enclosure maps from 1847 to 1848 to identify forests, slash and burn areas, and fields.

Cereal pollen, together with microscopic charcoal particles, has been used by numerous authors to identify slash and burn cultivation (Huttunen, 1980; Laul and Kihno, 1999; Lehtonen and Huttunen, 1997; Lindbladh and Bradshaw, 1998). This method does not allow for the determination of the exact location of swiddens inside the studied area. Stumps left after slash and burn have also been also used to identify former swiddens, but the authors did not describe how these were recognised (Lankia et al., 2012). The soil profiles of regularly cultivated land should be recognisable by a smoothly ploughed layer (Bobrovskii, 2010).

Soil charcoal deposits have also been studied in connection with soil fertility and the carbon cycle, greenhouse gases, and climate change (Jaffe et al., 2013; Hart and Luckai, 2013). In addition, soil charcoal could affect the carbon sequestration of soil organic material (Pluchon et al., 2016). Soil charcoal deposition caused by slash and burn cultivation has been studied more extensively in tropical countries and in the prehistorical context; in northern countries, deposits of soil charcoal have been examined in relation to forest fires (Wardle et al., 1998; Ohlson and Tryterud, 2000; Carcaillet and Talon, 2001). Macroscopic soil charcoal as a result of local burns has also been studied (Carcaillet, 1998; Ohlson and Tryterud, 2000; Lynch et al., 2004).

Soil charcoal is also assumed to be a marker of former boreal slash and burn cultivation, but the interpretation of soil charcoal deposits is still complicated (Halshall et al., 2018). Hokkanen (2006) used the presence of soil charcoal as evidence of slash and burn cultivation. Lagers and Bartholin (2003) used radiocarbon dating and charcoal stratigraphy to distinguish the charcoal which originated from cultivation. In Sweden, Weimarck (1968) described soil charcoal in the uppermost layer of the mineral soil as a result of slash and burn cultivation, and wildfire charcoal as a dark layer on the surface of the mineral soil. Bobrovsky (2010) suggested that the character of buried charcoal in forest soils does not reveal whether the fire that caused the charcoal deposition had been of natural origin, or from slash and burn cultivation. Ponomarenko et al (2018) provided a preliminary description of the characteristics of soils in former slash and burn sites using soil charcoal, phytoliths, soil pollen, and macrofossils.

3. AIMS AND HYPOTHESES OF THE STUDY

The main objective of the study was to estimate the effects of historical slash and burn cultivation on the formation of southern Estonian cultural landscapes and forest vegetation.

The specific aims of the study were:

- to estimate the extent of slash and burn cultivation in 19th century land use, and to describe the landscape characteristics of areas used for regular slash and burn cultivation (I, II)
- to determine the land cover/use changes of former slash and burn lands during the 20th century (I)
- to identify the effect of rotational slash and burn cultivation on modern forest vegetation (II, III)
- to describe the role of slash and burn cultivation in the formation of forest soil charcoal deposits, and to explore the methods used for identification of areas used for slash and burn cultivation (III, IV).

Hypothesis

- Slash and burn cultivation has been an important factor in the formation of southern Estonian cultural landscapes.
- The areas used for slash and burn cultivation have characteristic landscape features.
- Regular slash and burn cultivation had an effect on the formation of modern forest vegetation.
- Slash and burn cultivation has contributed to the charcoal content of boreal forest soils.
- There are relevant indicators that can be utilised to identify sites used for slash and burn cultivation.

4. METHODOLOGY

4.1. Study areas

The study was carried out in the Valga and Võru counties, southern Estonia (Figure 1), in Karula National Park (NP) (I, II, III, IV), Karula Pikkjärve Landscape Protection Area (LPA) and Paganamaa LPA (III, IV), Mõisamõtsa Nature Protection Areas (NPA) (IV), Pähni NPA (III, IV) and Haanja Nature Park (NaP)(I, III, IV). The study area climate is moderately continental. The average daily temperature is -5 °C in winter and 16 °C in summer. The annual precipitation is approximately 700 mm (Tarand et al., 2013). The soils are mainly sandy and loamy acidic soils formed from moraines on Devonian bedrock (Astover et al., 2012). Karula NP is located in Karula; Haanja NP and Paganamaa LPA are located in the Haanja Upland. Pähni NPA is flat, and Mõisamõtsa NPA has an undulating relief. Moraine kames and eskers have relative heights of up to 25–80 m. Of the three study regions, Karula NP and Karula Pikkjärve LPA were determined to belong to the Karula region, Haanja NaP to the Haanja region and Pähni NPA, and Mõisamõtsa NPA and Paganamaa LPA to the Paganamaa region.

4.2. Maps and map analysis

The study was entirely based on 62 cadastral maps from the 19th century that were dated 1851–1900 (scales 1:4200–1:52,000). Digital copies of maps were obtained from the National Archives of Estonia, and georeferenced. To determine the characteristic features and to analyse the land use changes in 20th century, 51 19th century farm maps and delineation maps of the Saaluse manor were digitised and used estimate the extent of slash and burn cultivation during the 19th century.

In the 19th century, maps depicted permanent arable fields, *buschland*s, hay meadows, pastures, vegetable gardens, forests, wetlands, and some less important land-use units. Only the main parcels of estates were digitised; hay meadows distant from the main farmland area were not included in the analysis because they were missing the recognisable landmarks required to georeference them. The following land use classes were determined for land use changes analyses: arable fields (including

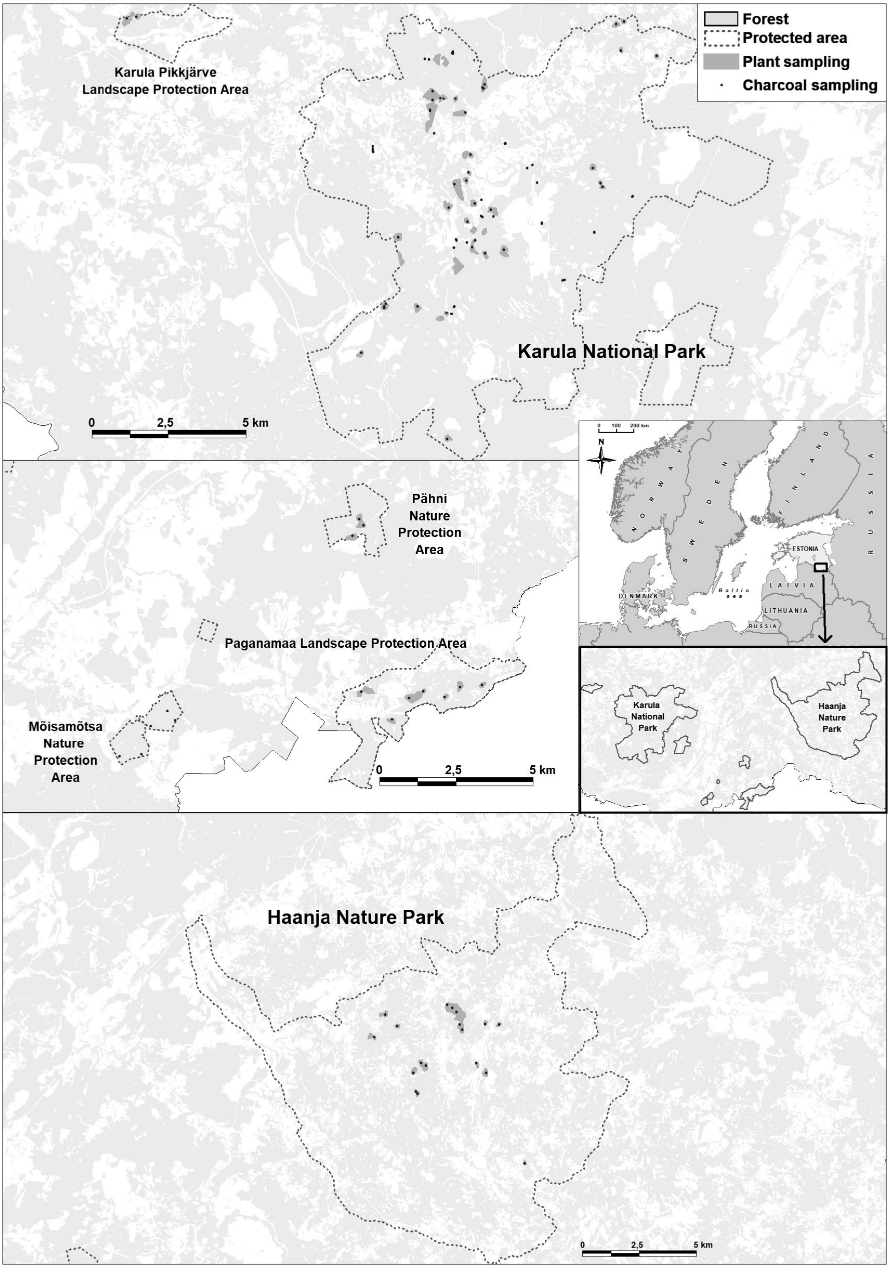

Figure 1. Study areas.

gardens, farmyards, and roads), grasslands (hay meadows and pastures), forest (coniferous and deciduous forests, and wetlands), and water.

To determine land coverage at the beginning of the 20th century, Russian one-verst map (from 1912 to 1922 at the scale 1:42,000) were used (Estonian Land Board, 2014a). A record of the start of the period of Soviet collective farms was obtained from the 1:50,000 topographical map completed in 1950s (Environmental Board of Estonia, digital archive). For the Soviet era, Cadastral Map from 1985 to 1987 (1:10,000) (Estonian Land Board, 2014a) were utilised. For modern land cover, the Estonian Digital Basic Map (1:10,000) was used (Estonian Land Board, 2014b). Four land categories were adopted to analyse land use changes following the common classifications on the maps: fields (arable fields, bare areas, buildings, and roads were included), grasslands, forests and wetlands (forest, scrub, felled areas, bogs, and fens), and 'waters'. To examine different scenarios of land use changes for vegetation and charcoal deposits, the land coverage on one-verst maps were grouped into three classes: open (fields and grasslands), transitional (shrubs and areas with sparse trees), and forests.

The rotational slash and burn cultivation plots were named *buschland* on 19th century maps, and therefore previous slash and burn sites are referred to in the present study as former *buschlands*. The stands located in areas mapped as forest in the 19th century were named former forest (Figure 2).

Figure 2. Fragment of a land use map of Karula manor (1867). EAA.3724.5.2803.

The analyses of the extent of slash and burn cultivation during the 19th century land use were carried out in Karula NP and Haanja NaP. The characteristic features and the land coverage changes of former *buschlands* in the 20th century were analysed in Karula NP. For each mapped period, the areas of determined land coverage classes were calculated. To follow the changes in land coverage classes, each class of the earlier map was overlaid with the later map and the changes were analysed. In order to reduce random errors, areas smaller than 0.1 ha were eliminated at every step during the comparison of periods.

To select forest stands for fieldwork, historical maps and digital map from the Forest Management Database (FMD) were compared visually. During additional surveys, land use during the 19th and 20th centuries were also verified visually. The FMD was used to determine the forest characteristics of former *buschlands*, to select suitable stands for fieldworks, to identify the age of dominant trees, and to identify stand areas, dominant tree species, and types of forest. The Estonian Digital soil map (Estonian Land Board, 2014c) was used to identify the soil characteristics of former *buschlands* and to check the soil type during fieldworks. This database consists of data on soil types classified according to the Estonian soil classification (Vabariigi digitaalse…, 2001). The names of soils were transformed corresponding to the World Reference Base, following Astover et al (2012).

MapInfo Professional 10.0 software was used for analysing and comparing the maps.

4.3. Fieldwork

Preliminary fieldwork was carried out in 2013, and involved visiting 20 former *buschlands* in Karula NP, to obtain an impression of their current appearance and to plan the fieldwork. To study the effect of slash and burn cultivation on the modern vegetation, the field work that included soil sampling was carried out during the summer months of 2014 and 2015 in Karula NP (47 forest stands), Pikkjärve (three forest stands), Paganamaa NPA (eight forest stands), Pähni NPA (three forest stands), and Haanja NaP (19 forest stands). In Mõisamõtsa NPA, soil sample pits were established in five forest stands and the landscape elements were recorded. In 2014 and 2016, additional soil sampling was completed in

15 sites (36 pits), and six soil trenches (size 55–65 × 120–160 cm) were established in Karula NP, to better understand soil charcoal deposition.

For the vegetation survey, 80 forest stands both from former *buschland*s (45 stands), and forests (35 stands) where the dominating trees layer was older than 90 years, were selected. Forest stand sizes larger than 0.5 ha were preferred. From the former forest sites, only *Oxalis* type forests, as determined by the results of the *buschlands* characteristics analysis, were selected (II). The observed stands in former *buschlands* belonged to more varied forest types: 31 (68.9 %) were *Oxalis* forest (the main type), 10 (22.2 %) were transitional *Oxalis-Vaccinium myrtillus* subtype forests, two (4.4 %) were *Oxalis-Vaccinium vitis-idaea* subtype, and two (4.4 %) belonged to the *Hepatica* type. Stands with fresh stumps were excluded to avoid any effect of recent forest management. In most observed forest stands, five vegetation plots were examined.

For additional survey of charcoal deposits tree ages, forest type, and plot size were not considered as preconditions, and dry oligotrophic forests were included. To obtain comparative information from sites with different land use histories, 12 soil pits in 19th century arable fields were established. Six pits were established in 19th century forest sites where wildfires took place approximately 10 years ago, and four pits were established in 19th century arable fields where experimental slash and burn cultivation had been carried out in 2007 and 2009 by The Estonian National Museum (Jääts et al., 2011). During the additional survey, sample pits were excavated at 12 sites in both upper and lower parts of hills (footslopes) to estimate the role of erosion in the accumulation of soil charcoal. The *buschland* soil trenches were excavated in sites where data on archaeological findings was available and well-developed field banks could be recognised. Forest sites for excavating trenches were selected in remote areas or difficult to access places that lacked any visible field edge banks. The location of charcoal sampling sites for species identification, radiocarbon dating and erosion effect estimation are presented in Figure 3.

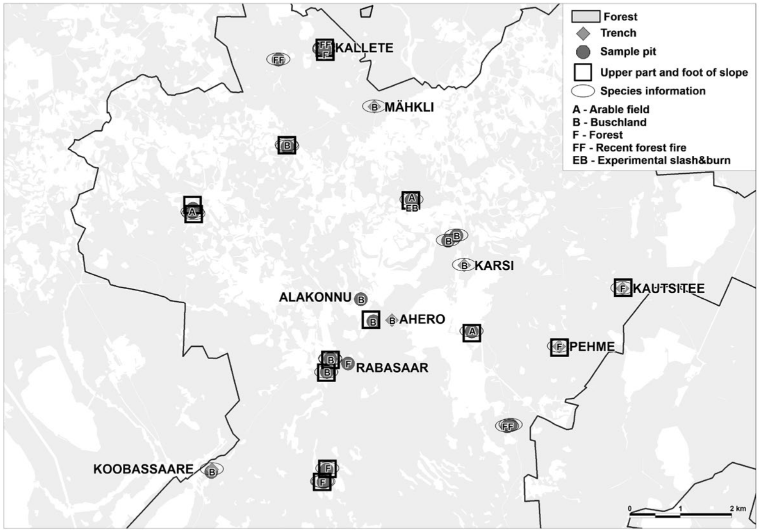

Figure 3. The location of charcoal sampling sites for species identification, radiocarbon dating and erosion effect estimation.

For vegetation surveys, the methodology of Bunce and Shaw (1973) was utilised. Vegetation sample plots were located randomly within the preselected forest stands, and plots of 200 m² were included for future analyses. The estimated abundances of regenerated trees and of bushes were recorded by species. The presence of bryophyte species was also recorded. Herbaceous plants were identified based on Leht (2010), and bryophytes were identified based on Ingerpuu and Vellak (1998). Tree diameters were measured at a height of 1.3 metres above ground level and were recorded by species. In every forest stand, the effect of former forest management and other human influences were estimated, and a 'summed general management index' was calculated.

The modern location of selected forest stands in the landscape were recorded (isolated stands in agricultural land, on the border of forest blocks, and in large blocks of forest). The locations of sample plots in relation to relief forms (flat lands, the tops of hills, footslopes, and slopes), and in the landscape (isolated, forest edge, and forest centre) were recorded. Landscape elements connected with former slash and burn cultivation, such as large relict trees, field banks, and traces of excavated pits (for storing turnips over winter) were recorded.

In every observed forest stand, a soil pit of 50 × 50 cm was dug according to field study methodology (Astover et al., 2013) as semi-excavation.

Soil texture, thickness of litter, and humus layer were recorded. Soil samples were collected for laboratory analysis from the humus layer, and from below the humus layer. The analysed properties were pHKCl, total nitrogen, organic C concentration, and soil specific surface area (the exact methods are presented in paper III).

To analyse the soil charcoal, deposits were visually estimated, and the amount and character of soil macroscopic charcoal (diameter from 1 to 2 mm) determined. Visual estimation did not allow for the calculation of the soil charcoal exact contents, but was a simple method for comparing the sites with each other. These were included in the charcoal analyses data from 106 soil pits. The scales used to estimate the amount and character of soil charcoal were determined and tested using preliminary soil pits that were not included subsequent analyses. For radiocarbon dating, charcoal samples were collected from two layers in five trenches and from four layers in the deepest trench, from soil pits of two former slash and burn cultivation sites (two layers) and two forest sites (one layer). The charcoal samples were taken for identification from the same layers of the trenches used for dating. Samples were also collected in 2016 from 24 soil pits at differing depths to identify the species composition (355 charcoal particles). The charcoal samples used for dating and species identification were taken from the trench wall with a scoop and stored in Minigrip bags.

The amount of charcoal in soil was estimated visually using the following scale: absent, scarce, medium, a lot. The upper and lower borders of layers containing charcoal, and the borders of layers containing the greatest amount of charcoal, were recorded. The sizes of charcoal particles were recorded using the following classes: diameter $\leq$ 2 mm, diameter 2–10 mm, diameter greater than 10 mm, clusters (layers or conglomerates with different particle sizes), and dark sooty layers. To characterise the diversity of charcoal, particles were analysed in addition to the sum of different charcoal size classes (except for sooty layers). The presence of charcoal with a clearly visible structure, signs of bleaching, and any micro-relief in soil pit location were recorded. The thickness of litter and humus layers were measured.

4.4. Data processing

As part of the vegetation survey, light conditions and the effect of tree layer the basal areas of trees were calculated for the most important tree species and for all species present. Additionally, the basal area of young spruces, equal to or less than 5 cm in diameter, were calculated to characterise light conditions beneath them, as well as in the basal area of dead standing trees.

For the vegetation analyses, three of the initially selected stands were each divided into two on the basis of different environmental characteristics. In total 83 sites were used, with an average 4.8 sample plots (range 2–8) per site. Therefore, the term site is used for the sampling locations in the present study.

In several sites in former forests, the field banks were recorded during the field work that are obvious indicators of cultivation. As the 19th century witnessed the decline of slash and burn cultivation, it was assumed that these signs of cultivation dated from prior to, not after, the 19th century, and that these sites were older slash and burn cultivation sites. Therefore, additional classifications of sites that reflected their land use history were utilised. The sites mapped as forest in the 19th century were divided into two groups: former forests without signs of cultivation were named 'continuous forests' and areas that were mapped as forest during the 19th century but had field banks present were named 'older *buschlands*'. Therefore, three groups were formed that characterised the time gradient: recent *buschlands* (mapped as *buschland* during the 19th century, n = 47), older *buschlands* (n = 11), and continuous forests (n = 25) (III). For charcoal deposits, the sites were grouped land use and by land use periods: pre-19th century land use (arable fields shown on 19th century maps, recent *buschlands*, and older *buschlands* together formed the group *buschlands*, former forests), 19th century land use (arable fields shown on 19th century maps, former *buschlands* and former forests), 20th century land use (open areas containing fields and meadows, transitional areas such as shrublands, sparse woodlands, and forests), and 21st century land use (open areas, experimental slash and burn cultivation fields (Jääts et al., 2011), forests, and recent wildfire sites).

The data measured at each vegetation sample plot were averaged by site. Both the dataset containing average plant coverage (restricted to ground layer herbaceous vegetation) and the dataset detailing presence of plants (for all species including trees and bushes) were analysed. The recorded vascular plant species were grouped according to their ecological preferences (ancient forest indicators by Wulf (2003), affinities for human impact (anthropophytes, apophytes, hemeradiaphores, and hemeraphobes by Kukk (1999)), and dispersal types to analyse the anthropogenic effects.

The recorded non-numerical environmental characteristics were converted to gradients. Soil types were ordered by the gradient of soil based on Lõhmus' forest ordination scheme (Asi et al., 2004). Forest productivity was used to place Delluvial soils into the gradient (Astover et al., 2012) at the same position as *Haplic Albeluvisols*.

The species of charcoal from burned trees were identified by author using a reference collection of charcoal samples and the online version of '*Wood Anatomy of Central European Species*'. Only particles larger than 5 mm in diameter were identified, using a light microscope.

For soil charcoal analyses, different tree datasets were used. The first dataset covered measured and calculated features for all 106 pits, the second consisted of comparable data from the hilltops and footslopes of the same site, and the third consisted of the tree species data from different sites and depths.

Radiocarbon dating was done at the Radiocarbon Laboratory, Institute of Geology, Tallinn University of Technology using the conventional method (conv) if the sample was in the range of 3–5 g of pure charcoal. Smaller samples were dated at the Poznań Radiocarbon Laboratory using the accelerator mass spectrometry radiocarbon dating (AMS). Oxcal 4.3 was used for calibration.

Historical settlements near the sample sites were identified from the 'Database of archaeological and place-lore sites', developed by the Centre for Archaeological Research and Infrastructure, Institute of History and Archaeology, University of Tartu.

4.5. Statistical analyses

Land use changes were analysed in Microsoft Excel 2010. All other statistical analyses were performed with R 3.2.3 software and results were considered statistically significant at $p \leq 0.05$.

Permutation analysis of variance (ANOVA) with the 'oneway_test' function in the 'coin' R package was used to compare environmental factors, and the coverage of herbaceous plant and bryophyte species grouped by historical land use. The same method was utilised to compare sites grouped by land cover types at the beginning of the 20th century, and by region. The data on the presence of herbaceous plants were analysed using Fisher's exact test. For analyses of herbaceous plants and bryophytes, the Bonferroni-Holm correction for multiple testing was applied using the R function 'p.adjust'. Principal component analysis (PCA) was used to discover basic patterns in vegetation coverage and to study the relationship of these patterns with environmental factors. The permutational multivariate ANOVA (perMANOVA) was used to test differences in vegetation coverage between land-use groups. Only the data concerning herbaceous layer vascular plant species present in more than 5 % of stands were included in the multivariate analyses.

Permutation analysis of variance (ANOVA) with the 'oneway_test' function was applied to compare charcoal variables by land use groups across different periods. The permutation test for dependent samples with the 'independence_test' function was used to compare charcoal variables in the upper and lower parts of hills. Variance partitioning analysis (VPA) was used to estimate the unique and shared parts of variance of charcoal characteristics, and how these related with land use for different time periods, soils, and relief characteristics. Additionally, another VPA was performed that considered different time periods and estimated their relative importance in relation to the charcoal data. To provide a better visualisation of VPA results, proportional Euler diagrams were fitted using the 'eulerr' function from the eulerr package.

The PCA was performed using the 'dudi.pca' function in the 'ade4' R package. VPA was performed using the 'varpart' function, and perMANOVA using the 'anosim' function in the 'vegan' R package. Both used permutation tests included in the 'coin' R package.

5. RESULTS AND DISCUSSION

5.1. The extent of slash and burn cultivation in 19th century land use and the characteristics of areas used for regular slash and burn cultivation

The results of the analysis of 51 farm maps indicate that *buschlands* occupied an important position in the Karula farmland in the 19th century, covering 35% of the total area, followed by grasslands (28%) and permanent arable fields (25%). *Buschlands* were even more common in the farmlands of Saaluse manor in the Haanja Upland, covering 45% of farmland. These results are somewhat higher than indicated in the 1881/83 land revision, which gave figures of 15.4% for Karula parish and 27.8% for Rõuge parish (Livländisches Landraths-Collegium, 1885), where Saaluse manor is located. The results of our map analyses were higher because the analysed areas were located in the hilliest parts of both parishes, where the portion of *buschland* would have been greater than elsewhere.

The round patches of *buschland* on 19th century maps coincide with hills (I). In flat areas, the *buschlands* were more distant from farm buildings. Flat land that was closer to farmyards was preferred for permanent arable fields. These location preferences were associated with dung transportation, which was complicated by steep slopes and long distances. The results of the PCA analyse (Figure 5) of fieldwork data confirmed that *buschlands* were associated with slopes and hilltops. As is known from other regions of Europe, slash and burn cultivation is associated with slopes (Weimarck, 1968; Sigaut, 1979; Sarmela, 1987), and south-eastern Estonian slash and burn areas are no different.

The comparison of 19th century maps with the map analysis of the Estonian Soil Map demonstrated that in Karula farmlands, the soils used for slash and burn cultivation were mainly *Haplic Albeluvisols* and *Albeluvisols* (53%) and *Regosols* (28%); *Luvisols* (8%) and *Podzols* (2%) were less commonly used. Other different soils accounted for 9%. Analysing the soils of forests stands selected for vegetation fieldwork, the same soil types were present, but the proportions were slightly shifted because the fieldwork was carried out only in mature forests. The less fertile soils were initially left as forest. Therefore, the proportion of less fertile soils was greater, and eroded soils were observed in only 15% of stands. *Haplic Albeluvisols* and *Albeluvisols* were the most common (68%); 8% of stands were mapped as *Luvisol*s, 7% as *Podzols*, and 2% as *Gleysols*. For slash and burn cultivation, moderately fertile forest soils were preferred. The *Oxalis* forest type, most common in former *buschlands*, is positioned in the centre of the forest ordination scheme (Lõhmus, 2004).

Areas used for swidden agriculture in south-eastern Estonia exhibit the same characteristics as in other regions. Moraine soils have also been noted to be common in slash and burn areas in Finland and Sweden (Soininen, 1959; Weimarck, 1968; Lovén and Äänismaa, 2006). Sigaut (1979) observed that European slash and burn areas typically had acidic soils

The *buschland* was a special land category that was not similar to others because of the specific utilisation, landscape features, and changeable land cover. Therefore, there is no reason to classify the *buschlands* as being the same as any modern land cover unit such as forest, grassland, or arable land in land change analyses.

5.2. Land cover changes of former slash and burn lands in 20th century

The large areas covered by *buschlands* meant that, in pre-industrial landscapes in southern Estonia, a remarkable proportion of the land was covered with young trees at different growth stages, dispersed fields, and fallows. This type of mosaic landscape had disappeared by the end of the 19th century and replaced by more homogenous land use patchworks with more definite land cover (e.g. to hay meadows without scrub or fully developed forests).

The map analysis showed that, at the beginning of the 20th century, the *buschlands* had disappeared; 72% of them had been converted into permanent arable land, 19% into forest, and 9% into meadows (Figure 4). At first, the *buschlands* were regarded as land reserved for agriculture, and mainly converted into arable land. At the end of the 19th century, peasants were allowed to buy their farms in perpetuity (Tarkiainen, 2008) and needed money to pay the loans for land purchase. The large area of extensively used *buschlands* provided an opportunity to rapidly increase both the area of arable fields and income. At the beginning of the 20th century, the timber value increased, and consequently the portion of forest cover increased in former *buschlands*.

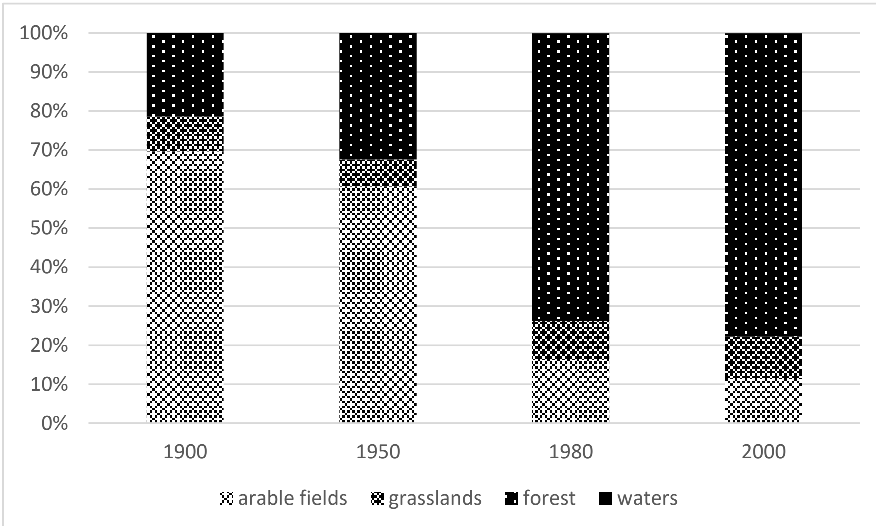

Figure 4. The land cover changes in *buschlands* during 20th century.

At the beginning of the Soviet period, in the 1950s, 60% of former *buschlands* were mapped as arable, 7% were mapped as grasslands, and 32% as forest. The analysis of the dominant tree layer age using the FMD data revealed that large-scale forest regeneration had started already during World War II (II). The portions of forests in former *buschlands* increased during the Soviet era and reached 71.5% of farmland. At the beginning of the 21st century, arable fields covered 11% and grasslands were 11% of former *buschlands,* while the portion of forests in former *buschland*s had increased to 76% (I). The rapid increase in forest cover which coincided with World War II (II) might have been a result of war events, and the massive Soviet deportations in 1941 and 1949 that were carried out in the Karula municipality (Merila-Lattik, 2005). Presumably the 1950s maps were drawn on the basis of earlier maps, and the fields with young forest cover were still considered open land. From the 1950s, mechanisation contributed to afforestation, especially on steep slopes that were unsuitable for mechanised tillage (I). The former *buschlands* were the most changeable land use and were the main source of secondary forests in the south-east Estonia. These forests now cover the round shaped kames and form a characteristic, picturesque landscape (I).

5.3. Modern vegetation in former slash and burn sites and in former forests

The analyse of the FMD revealed that *Oxalis* type mesotrophic boreal forests covered 54.4% of former *buschlands*, *Oxalis-Vaccinium vitis-idaea* transitional subtype forest covered 9.3%, and *Oxalis-Vaccinium myrtillus* transitional subtype forest 1.9%, on farmlands in Karula NP. The *Hepatica* site type covered 20.1% of *buschlands* forests, and the *Aegopodium* type 6.4%. Other less common types covered 7% combined of forests in former *buschlands*. *Oxalis* forests are typical of the former *buschlands*, 69% of this type of forests found on farmlands growing in former *buschlands* and is scarcer on other former land use categories (II). The fertile forest types were characteristic of the younger forests that have grown on sites that had been used for crop cultivation over a longer time-frame.

The results of the FMD analysis of Karula farmland were confirmed in other regions during the fieldwork. In the former *buschlands* 68.9% of sampled forest stands were of the *Oxalis* type, 22.2% were transitional *Oxalis-Vaccinium myrtillus* subtype forests, two (4.4%) were *Oxalis-Vaccinium vitis-idaea* subtype forests, and a further two (4.4%) were *Hepatica* type forests, according to the FMD. Fertile forest types occur less frequently there because only old-growth forests were included in the field survey. The less fertile lands were abandoned earlier, in some cases perhaps just after the cessation of swidden cultivation.

In Finland, *Myrtillus, Myrtillus-Oxalis, Vaccinium* and *Oxalis* forest types have been named (Heikinheimo, 1915; Soinien, 1959; Lovén and Äänismaa, 2006) as the most used for slash and burn cultivation. The forest types associated with slash and burn cultivation are fairly similar in Estonia and Finland, but are somewhat less fertile in Finland than in Estonia. The forest types are not precisely the same in Estonia and Finland, and it is therefore difficult to discuss the similarities without fieldwork.

The dominant tree species in the former *buschlands* in Karula farmlands according to the FMD were Scots pine (41%), silver birch (31%), grey alder (13%), Norway spruce (13%), and Eurasian aspen (2%). Birch and aspen were more common in young secondary forests, which regenerated on sites used as fields in the 20th century (II).

In forest stands observed during the vegetation survey, pine dominated *buschlands* in Karula NP and Paganamaa LPA (88% of sampled sites), but the spruce was the most common dominant tree (in 78% of sampled sites) in Haanja NaP by FMD. In the undergrowth, spruce was common everywhere; therefore in *buschlands* sites the average basal area of spruce was 10.72 m^2/ha, and pine was 9.67 m^2/ha, but these were 11.42 m^2/ha and 9.84 m^2/ha respectively, in forest sites. Pioneer species like birch and alder were not the dominant trees in former *buschlands*, while Čugunovs et al (2017) reported higher volumes of birch in former slash and burn site in comparison with forest areas in Finland. In the current study, the average basal area of birch was only 1.47 m^2/ha in *buschlands* and 1.86 m^2/ha in forests, and were most abundant in the forests of Pähni NPA.

Pine is not naturally typical for the *Oxalis* forest type; spruce is considered to be dominant there (Lõhmus, 2004). The prevalence of pine in these forests could be explained by plantations at the end of the 19th century. Abandoned slash and burn fields may have been colonised by pines in the manner described by Heikinheimo (1915). After the collapse of Soviet collective farms, abandoned arable fields in the eroded kames could be observed becoming overgrown with numerous species, including pines.

Acer platanoides L., *Alnus incana* (L.) Moench, *Populus tremula* L., *Padus avium* Mill., *Quercus robur* L., *Salix caprea* L., *Fraxinus excelsior* L. were found frequently in *buschlands* and could be a legacy of the recovery period that occurred after the cessation of slash and burn cultivation. However, former *buschlands* are often located in isolated patches and on forest edges, and this could also have promoted the spread of deciduous trees. In Karula, it is notable that the young broad-leaved trees that are common near the farmyards are the same species that have been planted as greenery.

Paal et al (2011) found *Populus tremula*, *Alnus incana*, and broad-leaved trees to be more abundant in sites where former transitional or agricultural lands had been located, but *Padus avium* was found to be more frequent in continuous forests. In contrast, Sepp and Liira (2009) classified *Populus tremula* as characteristic species of near-natural forest. In abandoned fields in Karula NP, the regeneration of *Alnus*, and to a lesser extent *Populus*, is common today. *Padus* form the dense undergrowth layer in 19th century arable fields that became overgrown with alder during the Soviet era. These controversial observations do not allow for the conclusion that the greater number of deciduous trees is the result of slash and burn cultivation.

A comparison of the average presence of vascular plants in the ground vegetation (excluding seedlings of trees) of recent *buschlands*, older *buschlands*, and continuous forests revealed differences (univariate analyses, $p<0.05$) for 17 species. Several of the most frequently occurring species (found in more than 10% of the sites) were present at different rates in recent *buschland*s, older *buschland*s, and continuous forests: *Calamagrostis arundinacea* (L.) Roth (0.30, 0.64, and 0.72, respectively), *Convallaria majalis* L. (0.19, 0.36, and 0.60, respectively), *Fragaria vesca* L. (0.93, 0.82, and 0.72, respectively), *Polygonatum odoratum* (Mill.) Druce (0.04, 0.09, and 0.24, respectively), *Crepis paludosa* (L.) Moench (0.04, 0.18, and 0.24, respectively), and *Galeopsis tetrahit* L. (0.15, 0.36, and 0.44, respectively). A comparison of the average coverage of species in the ground layer revealed differences in 19 species (III). With the exception of *Fragaria vesca* and *Lysimachia vulgaris* L., the same frequent species had also differences in coverage. Additionally, *Melampyrum pratense* L., *Equisetum sylvaticum* L. and *Vaccinium vitis-idaea* L. showed greater coverage in continuous forests. The differences in plant species coverage and presence were small, because once the correction for multiple testing had been applied, only differences in the presence of *Populus tremula* were still statistically significant.

In forests, *Calamagrostis arundinacea* and *Convallaria majalis* were more frequent species, neither of which are specific to natural forests in Estonia. *Calamagrostis arundinacea* is favoured by forest management (Zobel et al., 1993; Uotila and Kouki, 2005) and is common in abandoned slash and burn fields in Koli (Loven and Äänismaa, 2006). *Convallaria majalis* grows not only in forests, but also in dry alvar sites in Estonia. In contrast, Paal et al (2011) found *Calamagrostis arundinacea* and *Convallaria majalis* to be more abundant in long term forest.

Fragaria vesca (wild strawberry) is a common species in habitats with good light conditions (Leht, 2010) and is not specific to slash and burn cultivation areas. However, clear-cut areas are favoured habitats for wild strawberry in Estonia. In eastern Finland, *Fragaria vesca* is particularly associated with grassland vegetation that developed due to the grazing of swiddens after cultivation (Loven and Äänismaa. 2006). Therefore, the more frequent presence of *Fragaria vesca* could be associated with subsequent grazing phases and the later afforestation of recent *buschlands*. In contrast, continuous forests had greater coverage of *Vaccinium vitis-idaea* and *Dryopteris expansa* (C. Presl) Fraser-Jenk. & Jermy. The former was common in dry pine forests in Karula region, and the latter in old spruce forests in Haanja.

Six species of bryophytes showed differences in their average presence between the groups of study sites with different land use histories: *Brachythecium oedipodium* (Mitt.) A. Jaeger, *Eurhynchium angustirete* (Broth.) T.J. Kop., *Plagiomnium affine* (Blandow ex Funck) T.J. Kop., and *Rhytidiadelphus triquetrus* (Hedw.) Warnst. were more common in recent *buschlands*, whereas *Plagiochila asplenioides* (L.) Dumort. and *Polytrichum formosum* Hedw. were more common in continuous forests. Bryophytes more common in *buschlands* were more likely to be associated with deciduous trees and humus rich soils; *Brachythecium oedipodium*, which is common in different types of forests, were found in greater quantities there. Of the forest bryophytes, *Plagiochila asplenioides* is not as demanding as *Polytrichum formosum*, but it also grows preferentially in the humus-rich soils (Ingerpuu and Vellak, 1998). After applying the correction for multiple testing, only the differences in the presence of *Brachythecium oedipodium* remained statistically significant.

The main soil characteristics were similar for both former slash and burn sites and forests. No differences were found in soil pH, nitrogen, organic C, and specific surface area. These results demonstrate that the initial rise in pH after burning (Viro, 1974; Pyne et al., 1996; Delgado-Matas, 2004) had vanished, but do not confirm that the soil in former slash and burn fields was particularly bleached (Reintam and Moora, 1983). Therefore, the fire effect could not be the cause of the observed vegetation differences. Average litter thicknesses were different between recent *buschlands* (4.79 cm), in older *buschlands* (6.55 cm), and in continuous forest (6.12 cm) (p= 0.016). The average thickness of humus layer was observed to be different between the two historical land use groups, and was thicker in former *buschlands* than in forests (15.1 versus 12.1, respectively, p=0.033.) These results are similar to the results of Čugunovs et al (2017). It is probable that insufficient time has elapsed since their last use for cultivation to allow for the final recovery of the litter layer. In *buschlands*, the litter layer had been destroyed by burning and tillage. After their abandonment, the recovery of the litter layer required time, and the process is still ongoing. The soil biota of fallows, pastures, and deciduous forests is different from that of coniferous forests and promotes the formation of a humus layer. In many *buschland* sites, bleached layers both above and below the humus horizon were observed, indicating the land use changes.

Myrmecochores were more common in older *buschlands* and continuous forests (1.27 and 1.12 species per site on average, respectively) and less common in recent *buschlands* (0.79 species per site on average, $p = 0.030$). The difference in the number of myrmecochorous species shows that these slowly spreading species have not yet completely colonised former slash and burn areas. There were no statistically significant differences in species richness for any other examined ecological groups. Whilst it was expected that ancient forest species, hemeraphobes, and hemeradiaphores would be present in lower numbers in former *buschlands*, this could not be proved. The *buschlands* were not suitable habitats for the characteristic species of old-growth forests. The *buschland* tree layer contained young deciduous trees, and ground conditions differed a lot from that of mature coniferous forests that had been continuous forests. It seems likely that the recolonisation of the former *buschlands* by forest species after their abandonment has been successful due to the mosaic farm landscape, in which the different land uses formed a heterogenous patchwork of small land use units where the slash and burn areas were often located closest to forest blocks.

For ground vegetation, the differences were more obvious using multivariate analyses, which take into account the whole set of species. Comparing the presence of different plant species, including trees, bushes, and bryophytes, the results of the perMANOVA showed significant differences between former *buschlands* and forests; the variability accounted for was 5.2% of total variation ($p=0.004$). Compared with recent *buschlands*, the variability for older *buschland*s and continuous forests was 4.1% ($p=0.004$). The differences in vegetation between site groups with different slash and burn histories were also proven using other statistical methods (III).

The comparison of land cover types at the beginning of the 20^{th} century (open *versus* transitional *versus* forest) revealed statistically significant and slightly stronger effects on the presence of plant species in comparison with 19^{th} century land use. The results of perMANOVA showed a variability that accounted for 7.2% of the total variation ($p=0.002$).

The vegetation differences were the clearest between regions: plant presence analyses using perMANOVA showed that regions showed a variability that accounted for 13.6% of the total variation ($p=0.001$), and plant coverage analyses showed a variability that accounted for 11.7% of the total variation ($p=0.001$). This can be explained by the slightly different soil conditions, as in Haanja Upland the moraines are more calcareous than elsewhere, and also by the dominance of spruce in the tree layer.

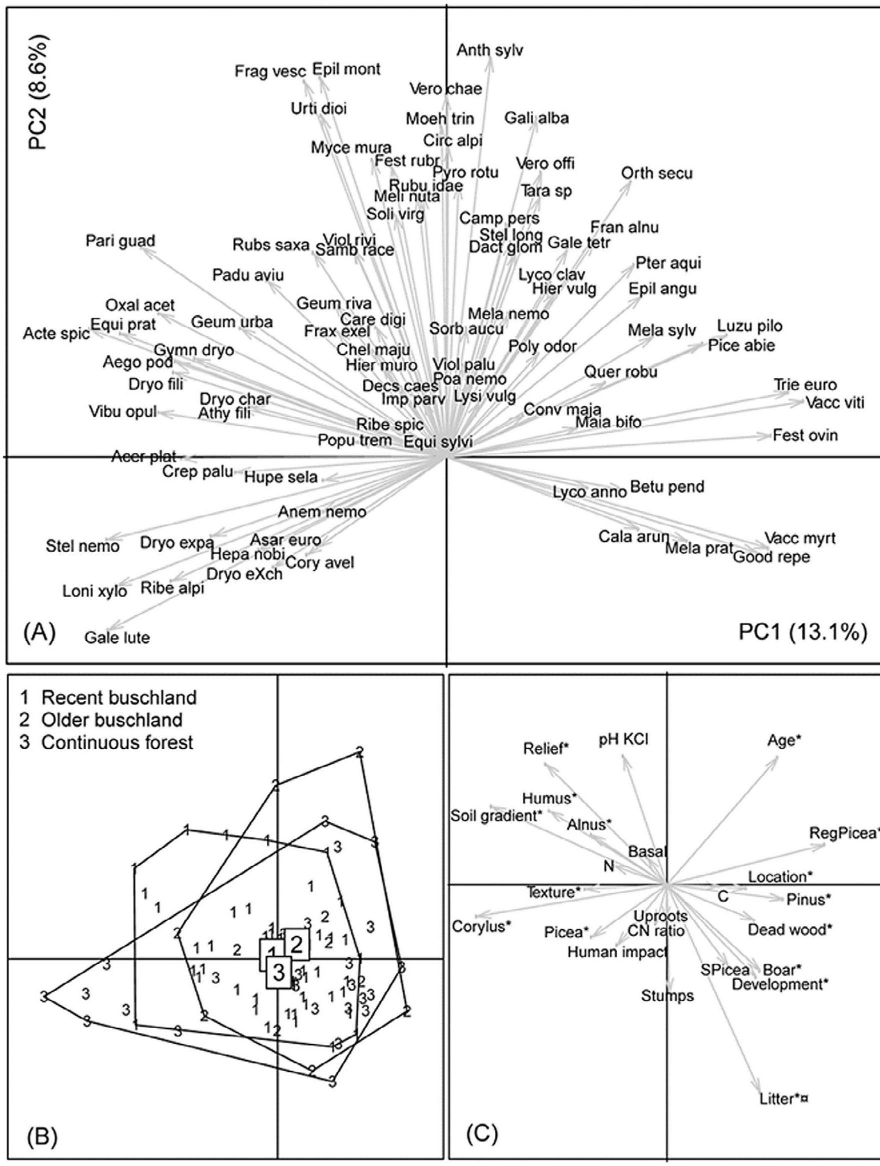

Figure 5. Results of principal component analysis of plant species found in at least 5 % of study sites: (A) lengths and directions of arrows denote the weights of plant species concerning the first two principal components; (B) location of study sites on the plane of the first two principal components, each site is marked with a land use group number, centroids of different groups are denoted by the larger-font numbers in boxes; (C) correlations of selected landscape and soil characteristics with the first two principal components, statistically significant ($p < 0.05$) correlations with PC1 and PC2 are denoted with * and ¤, respectively. The abbreviations of plant names and environmental factors are presented in paper III.

Similar conclusions have resulted from the PCA, which revealed that 21.7 % of the total variability of coverage by regular herbaceous layer species could be described by the first two principal components (PC). The first PC reflects differences in light conditions and soils conditions. On the left side are species that favour fresh and less acidic soils (Figure 5A), and on the right side are species that prefer dry habitats with better light conditions. The correlation analyses of principal components and environmental factors (Figure 5C) demonstrated the same pattern, showing a significant negative correlation between the PC1 and basal area of *Corylus avellana* L. and *Picea abies,* species that cause poor light conditions. PC1 was also negatively correlated with soil gradient, soil texture, thickness of humus layer, and relief. PC1 was positively correlated with the ages of the dominant trees, the summed basal area of pine, litter thickness, effects of wild boars, average number of fallen dead tree trunks, dense spruce regeneration, distance from forest boundary, and 1912–1922 land cover. The vegetation connected with the PC2 (Figure 5A) seems to be associated mostly with human impacts. An environmental factors analysis showed that PC2 was significantly and negatively correlated only with litter thickness; the species on the upper part of Figure 5A tend to be more dominant in sites that have a lesser litter layer thickness. An ANOVA test comparing the values of the first two principal components in different land use history groups showed no statistically significant differences in the case of tree species or in the two groups (all p-values>0.3), and therefore the pattern described did not reflect 19th century land use effects. The results of the PCA demonstrated that environmental conditions determine the ground vegetation more than historical rotational slash and burn cultivation.

In Figure 5B, continuous forests are in the most left and most right side of the PC 1 axis, in comparison with former *buschland*s. In the Haanja region, the continuous forests were more fertile, had less sunlight, and the dominant tree was spruce. In the Karula and Paganamaa regions, continuous forests tended to be drier, species-poor pine forest. The *buschlands'* vegetation was more similar in all three regions.

In former forests, some species not typical to the forests, such as ruderal *Galeopsis tetrahit* as well as alien species such as *Impatiens parviflora* DC., meadow species like *Melampyrum nemorosum* L., *Anthriscus sylvestris* (L.) Hoffm., and *Dactylis glomerata* L. were found. This could be due to the effects of forest management, which favour the light-demanding species

(Liira and Sepp, 2009). The estimated human impact and number of cut stumps in sample plots were the same in former *buschlands* and in forests. Forest management may have been promoted the presence of light-demanding species, which were expected to be present in greater amounts in *buschlands* as remnants from open land cover periods, and therefore changed the vegetation.

In Estonia during the 19th century, rotational slash and burn cultivation was used in young woods. These sites had previously been covered by grasslands and deciduous trees for centuries. The recovery of forest vegetation in Estonian slash and burn sites is thus more dependent on colonisation, rather than on seed banks or preserved regenerative parts of forest species. The grassland vegetation and deciduous tree cover promote the development of a humus layer that on average was deeper in former slash and burn sites. The effect of rotational slash and burn cultivation therefore must have been greater than the effect of a single slash and burn cultivation event in an old forest, which was more similar in effect to an intensive forest fire.

As permanent changes in soil properties and specific fire-prone plant species were not found, we cannot conclude that the observed differences in vegetation were caused directly by slash and burn cultivation. In contrast, Bobrovskii (2010) argued that slash and burn cultivation and the accompanying frequent forest fires have resulted in the formation of specific pyrogenic ecosystems and landscapes. The smaller number of myrmecochores in *buschlands* and the greater effect of the 20th century land cover on vegetation variability, both observed in the present study, suggest that the former *buschlands* are in the process of recovery, and are more similar to post-agricultural forests than they are to semi-natural habitats that require permanent management to maintain suitable environmental conditions.

In former slash and burn sites, both pioneer and meadow species have been observed in Finland (Loven and Äänismaa, 2006). In Finland, studies on slash and burn areas are mostly from the eastern part of the country, in the Savo and Karelia regions, where the practice was still common until the 1930s (Tarkiainen, 2014). Therefore, it seems likely that the Finnish studies reflect the effects of 20th century slash and burn cultivation. The majority of the plant species named as typical of the former swiddens areas (Myllyntaus, 2002; Loven and Äänismaa, 2006) are light-demanding meadow species that are not common in mature coniferous forests. *Rubus saxatilis* L. and *Oxalis acetosella* were noted to be characteristic of slash and burn cultivation in Finland by Myllyntaus (2002), but these species were equally represented in former *buschlands* and forests in the present study. One named species, *Geranium bohemicum* L., is fire-prone, but was not found in the present study. *Rubus arcticus* L.is rare in Estonia and grows in wet habitats. In Estonia, regular slash and burn cultivation disappeared earlier than in Finland (Jääts et al., 2010) and it has not been proved that any specific vegetation is associated with former slash and burn cultivation in the present study. Therefore, it is possible that the effects of slash and burn cultivation decrease over time and could also disappear in the future in Finland. The results of our study confirm the suspicions (Heikinheimo, 1915; Myllyntaus and Mattila, 2002) that the effect of swidden cultivation may not be permanent.

The effects of slash and burn cultivation on species diversity have been more important at the landscape level, because it caused the creation of mosaic landscapes of open areas and promoted the growth of deciduous trees.

It is likely that some stands without visible traces of cultivation observed in the present study have been used for single slash and burn cultivation events in earlier times. As is known from historical sources and pollen analyses, the cycle between burnings was longer in earlier times. Therefore, these effects must have been weaker than the effects of 19th century rotational slash and burn cultivation. The analyses of the three groups (recent *buschlands,* older *buschlands*, and forests) did not reflect transitional patterns of vegetation along a time gradient.

The observed differences were not so radical that the distinction of a special forest type would be justified, and there is no reason to believe that ancient slash and burn cultivation had a greater impact on vegetation (see Laasimer, 1958). The results of the present study correspond with the opinions of authors who have commented on the vegetation impoverishment of *buschlands* (Rõuk, 1995; Paal, 1997). These results make it possible to predict that young forests in former *buschland*s (II) could also recover in the future. This conclusion is controversial, given that numerous authors have described how secondary forest in former agricultural land have different vegetation from that of ancient forests, even long after abandonment (Hermy et al., 1999; Dupouey et al., 2002; Verheyen et al., 2003; Hermy et al., 2003; Hermy and Verheyen, 2007; Matuszkiewicz et al., 2013 etc).

5.4. The role of slash and burn cultivation in formation of soil charcoal deposits

Charcoal was found in 102 observed sites (97.1 %), in sites with different land use histories. The greatest average maximal depth of charcoal (40.6 cm) was found in former arable fields, while in former *buschlands* the average maximal depth was 25.6 cm and in forests it was 19.9 cm. The minimal charcoal depth was smallest in forests (10.0 cm in average), then in former *buschlands* (13.2 cm), and arable fields (20.9 cm). Characteristics connected with the depth of charcoal were statistically different between the sites with different 19th century land uses, but there were no differences in the thickness of the charcoal-rich layer. No differences were found in the estimated abundance and in the occurrence of charcoal particles of different size classes in former *buschlands* and forests (Table 1). The charcoal depths were least in recent forest fire sites (minimal average depth 1.5 cm) and in the experimental slash and burn field (2.0 cm), demonstrating that at the charcoal is initially located closer to the soil surface and is later translocated deeper by various mechanisms.

Table 1. Average values of studied charcoal characteristics according to different land use groups, and statistical significance of between-groups differences (permutation ANOVA; p-values indicating statistically significant differences are presented in bold face).

Charcoal characteristics	19th century land use				21st century land use				
	Arable land	Busch-land	Forest	p-value	Open	Experi-mental slash and burn	Forest	Recent forest fire	p-value
Charcoal minimal depth, cm	20.9	13.2	10.0	**<0.001**	20.9	2.0	11.7	1.5	**<0.001**
Charcoal maximal depth, cm	40.6	25.6	19.9	**0.002**	40.6	19.0	23.0	31.7	**0.017**
Charcoal minimal depth according to the to the upper border of humus layer, cm	20.9	8.7	5.0	**<0.001**	20.9	2.0	7.0	-2.8	**<0.001**
Charcoal maximal depth according to the upper border of humus layer, cm	40.6	20.8	15.0	**0.001**	40.6	19.0	18.1	27.3	**0.002**

Thickness of layer containing charcoal, cm	19.8	12.3	10.0	0.099	19.8	17.0	11.2	30.2	**0.002**
Upper border of charcoal-rich layer, cm	32.1	14.9	12.2	**<0.001**	32.1	2.3	13.7	11.8	**<0.001**
Lower border of charcoal rich layer, cm	38.8	21.1	17.6	**<0.001**	38.8	9.5	19.5	19.5	**<0.001**
Thickness of charcoal rich-layer, cm	6.6	6.4	5.5	0.614	6.6	7.0	6.0	7.7	0.751
Upper border of charcoal-rich layer according to the upper border of humus layer, cm	32.1	10.4	7.2	**<0.001**	32.1	2.3	8.9	7.5	**<0.001**
Lower border of charcoal-rich layer according to the upper border of humus layer, cm	38.8	16.6	12.6	**<0.001**	38.8	9.5	14.8	15.2	**<0.001**
Estimated amount of soil charcoal (0–3)	1.8	1.9	1.7	0.497	1.8	2.5	1.8	2.3	0.140
Presence of charcoal pieces with diameter 0. 1–0.2 cm	1.0	0.9	0.8	0.237	1.0	1.0	0.8	1.0	0.551
Presence of charcoal pieces with diameter 0.2–1.0 cm	1.0	0.9	0.8	0.551	1.0	1.0	0.9	1.0	0.726
Presence of charcoal pieces with diameter more than 1.0 cm	0.4	0.5	0.4	0.383	0.4	0.8	0.4	0.5	0.672
Presence of charcoal clusters in soil	0.3	0.3	0.3	1.000	0.3	0.8	0.3	0.3	0.327
Size diversity of charcoal fragments	2.6	2.5	2.3	0.370	2.6	3.5	2.4	2.8	0.149
Presence of sooty layer	0.1	0.1	0.2	0.897	0.1	0.0	0.1	0.3	0.375
Presence of charcoal below humus layer	0.5	0.5	0.6	0.865	0.5	0.5	0.6	1.0	0.153
Presence of charcoal fragments with undisturbed structure	0.3	0.4	0.3	0.332	0.3	1.0	0.4	0.7	**0.033**

The depth of charcoal in former *buschlands* was in between depths found in arable lands and forests, which is consistent with historical land tillage intensity. In arable fields, the location of charcoal is changed by mechanised cultivation. The average maximal depth of the charcoal-rich layer from the mineral soil was deepest in arable fields (38.8 cm), then in former *buschlands* (16.6 cm), and least shallow in former forests (9.7 cm). The depth of charcoal in former *buschlands* could not be explained only by ploughing and harrowing with traditional tools (depth 5–10 cm) but was probably also attributable to the activity of soil fauna that are more common in lands with deciduous trees and grassy vegetation than they are in coniferous forests. The depth of charcoal must be examined from the mineral soil, because the formation of a litter layer lowered the charcoal layer.

The differences in total quantity of soil charcoal in former slash and burn lands and in permanent forests requires further study, because only macroscopic charcoal was examined in the present study. Nonetheless, Hashall et al (2018) have reported that macroscopic charcoal represents the majority of soil charcoal. Differences in the amount of charcoal were found between the lower and top parts of slopes, showing the effect of horizontal soil translocation (IV). The formation of field banks, which consist mainly of humus with dispersed charcoal pieces, is also due to horizontal translocation. Layers of microscopic soot like charcoal formed by water transportation were also found in lower horizons of trenches, both in former *buschlands* and forests (IV).

The location of charcoal was most connected with observed soil properties (soil type, texture, humus thickness, litter thickness, and signs of bleaching), and then with land use. As the land use is closely related to the soil properties, almost 19 % of the charcoal variability correlated with overlapping effect of these two factors. Of these, 21.4 % of charcoal variability correlated with soil properties and 9.9 % correlated with land use history (Figure. 6A).

The land use during the 21st century had the strongest effect, explaining 24.3 % of charcoal variation (Figure 6B). The effects of land use in earlier centuries were smaller (8.0–10.3 %) and coincided both with each other and with 21st century land use. This overlapping demonstrates the continuance of land use over time.

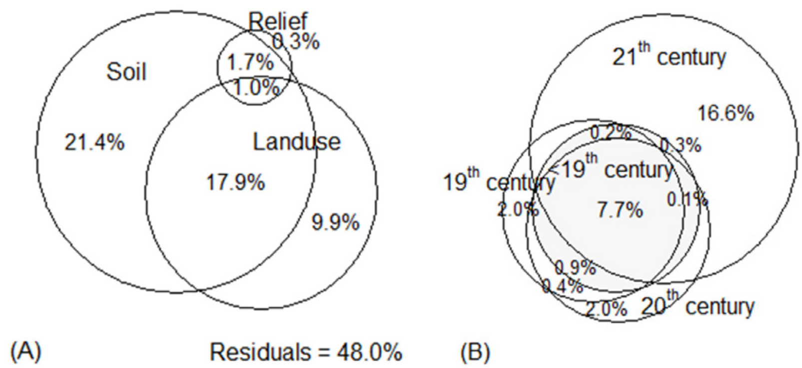

Figure 6. Results of variance partitioning analysis illustrated as a Euler diagram. (A) The proportion of variation in charcoal characteristics accounted for by soil parameters, relief, and land-use, and their intersections; (B) the proportion of variation in charcoal characteristic explained only by land-use, divided into parts according to the land-use periods. The graphical fit in (B) is not ideal but is proportionally correct: the root mean square error of the illustrated proportions is 0.5 %.

In former slash and burn sites, 50.3 % of identified charcoal particles were pine and 24.3 % spruce, 20.7 % of particles were from deciduous trees (Figure 7.) In former forests, pine charcoal (69.8 % of all identified particles) was more common, while an important proportion was occupied by non-woody charcoal. In former arable fields, spruce charcoal particles (54.6 % of particles) were most numerous, and charcoal from deciduous trees composed 25 % of all particles. The larger amount of spruce charcoal particles correlates well with pollen data (Poska et al., 2017), that shows the decline in spruce at the time of agricultural expansion. Former *buschlands* were expected to have more deciduous charcoal, as suggested by descriptions of *buschland*s in the literature (Ligi, 1963). The considerable proportion of pine charcoal was also found in *buschlands* in another study (Ponomarenko et al., 2018), and it can be inferred that pine may be important in the regeneration of tree cover in the rotation cycle of slash and burn cultivation. On the other hand, Halshall et al (2018) suggested that pine charcoal is resinous and more resistant than spruce charcoal.

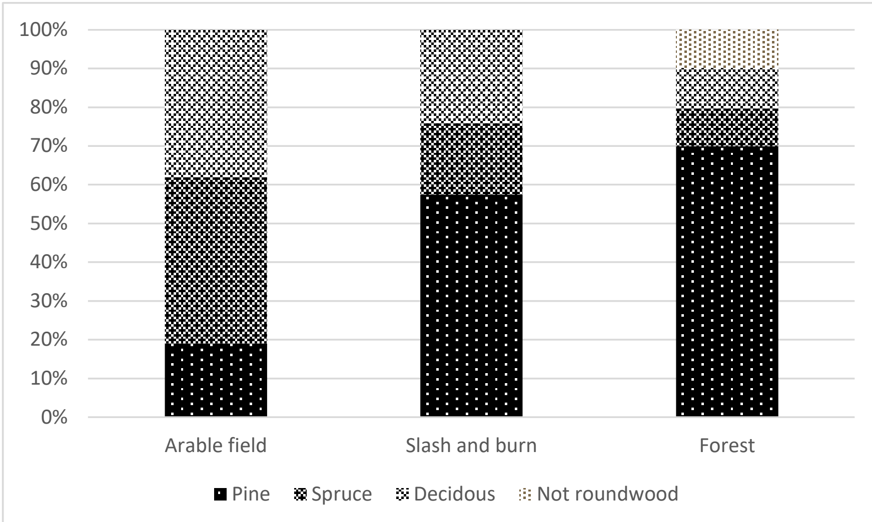

Figure 7. Species composition of charcoal from soils with different land use histories.

The weighted average dates of charcoal from humus layer of former *buschlands* are 1566–1805 calAD (Table 2), and numerous calibrated dates may extend out of range. These dates correlate well with literature data on the wide use of regular slash and burn cultivation (Ligi, 1963). The oldest charcoal was dated 4940±50 BP and was found from a forest site. The location of charcoal in the assemblage and comparison with archaeological findings from the study area, demonstrated that the oldest charcoal was caused by wildfire (IV).

The charcoal from mixed transitional layers from Karsi (weighed average date 747 calAD) and Mähkli (980 calAD) likely represent the first land occupation for slash and burn cultivation, whereas charcoal from a similar transitional layer in an Ahero trench was too old (2126 calBC) to originate from cultivation. To interpret the soil charcoal dates, information on relevant, local archaeological findings is useful.

Two sites remain unclear, mapped as forest in the 19th century, with charcoal dated 1582 calAD and 1672 calAD located in the podzol, but close to the contemporary settlement; especially considering the inbuilt carbon dating error. The mixed layer in the soil profile of the site Rabasaar (Table 2) suggested a weak effect of cultivation.

Table 2. The radiocarbon dates of soil charcoal samples

Site	Excavat. type	Land use in 19th century	Depth, cm	Character of charcoal	Soil layer	Soil type in site	Dating method	Date BP	Calibrated AD (probability 95.4%) from	Calibrated AD (probability 95.4%) to	Weighted average calAD	Error of weighted average calAD	Nearest historical settle-ment	Period of settlement	Distance of excavation from settle-ment, km
Karsi	trench	SB	14	dispersed	humus	sand, Haplic Albeluvisol	AMS	160±30	1664	...	1796	85	Ähijärve	RIA; LIA	1,2
Karsi			52	dispersed layer	transitional from humus to eluvial		con	1278±55	655	879	747	62			
Koobassaare	trench	SB	20	dispersed	humus	sand, Haplic Albeluvisol	AMS	180±35	1652	...	1788	89	Apja	LIA	1,5
			60–80	single pieces	illuvial		con	923±55	1017	1221	1112	57			
Ahero	trench	SB	16–0	dispersed	humus	sand, Haplic Albeluvisol	con	211±55	1522	...	1755	111	Alakonnu	MA	0,6
Ahero			40–45	dispersed layer	transitional from humus to eluvial		AMS	3730±35	-2276	-2028	-2126	61			
Mähkli	trench	SB	20–37	dispersed	humus	sand, Podzol	AMS	315±30	1484	1648	1566	47	Mähkli	PreRIA; RI; LIA; MA	0,9
			40–60	dispersed	humus		con	316±65	1442	...	1575	86			
	trench		75–110	dispersed layer	mixed transitional		con	1050±50	881	1151	980	59			
			130–165	dispersed and small clusters	eluvial		con	3861±50	-2471	-2155	-2336	82			
Kautsitee	trench	forest	10–15	dispersed	eluvial	sand, Podzol	AMS	810±30	1169	1270	1228	27	Ähijärve	RIA; LIA; MA	3,3
		forest	15–30	single small	transitional from eluvial to illuvial		AMS	1505±30	431	635	554	47			
Pehme	trench	forest	4–17	dispersed layer	eluvial	sand, Podsol	con	250±50	1483	...	1672	119	Ähijärve	RIA; LIA; MA	1,6
		forest	30–40	single	illuvial		AMS	4510±40	-3361	-3090	-3216	83			
Koobassaare	pit	SB	0–18	dispersed	humus	sand, Haplic Albeluvisol	AMS	95±30	1682	...	1789	89	Apja	LIA	1,5
			18–35	single	illuvial		AMS	925±30	1026	1182	1101	42			
Alakonnu	pit	SB	7–20	dispersed	humus	sand, Haplic Albeluvisol	AMS	140±30	1669	1945	1805	82	Alakonnu	MA	0,2
			20–50	dispersed	illuvial		AMS	185±30	1650	...	1786	90			
Rabasaar	pit	forest	20–30	dispersed and dispersed layer	mixed eluvial	sand, Podzol	con	297±50	1464	1796	1582	77	Kolski	MA; EMA	0,8
Kallete 4	pit	forest	33	cluster	illuvial	sand, Podzol	con	4940±50	-3913	-3639	-3731	63	Mähkli	PreRIA; RI; LIA; MA	1,7

Dates that are coloured red are out of range. PreRIAR–Pre-Roman Iron Age (500 BC–50 AD); RIA–Roman Iron Age (50–450 AD); LIA–Late Iron Age (550–1200 AD); MA–Middle Ages (1200–1550 AD); EMA–Early Modern Age (1550–1800 AD) SB–slash and burn cultivation site in the 19th century, forest–forest in 19th century; AMS–accelerator mass spectrometry radiocarbon dating, con- conventional radiocarbon dating

5.5. Methods for the identification of areas used for slash and burn cultivation and the extent of slash and burn cultivation

During the present study, different methods for the identification of former slash and burn cultivation sites were used and assessed. The 19th century maps were found to be useful for identifying former slash and burn sites. To detect the continuous forests, the maps are not perfect because, as became obvious during the fieldwork, in some 19th century forests sites the landscape elements, especially field banks, revealed earlier cultivation.

Landscape elements associated with former slash and burn cultivation were lynchet-like field banks (terraces), which were present in 42 (i.e., 89.4 %) analysed former *buschland* sites but were also present in nine former forest sites (22 % of forest sites). These field banks are formed by to the horizontal translocation of soil caused by tillage. Field banks are typical of repeated cultivation, and did not indicate the presence of single slash and burn cultivation events. The possibility that some field banks are the result of 'ordinary' cultivation without burning in other regions where swidden agriculture had not been so widespread cannot be excluded. In flat lands, outstanding field banks did not develop. Several types of landforms representing traces of ancient cultivation have been thoroughly described and classified in England (Hoskins, 1970). In the Nordic countries, field banks or terraces have been associated with ancient tillage (Maaranen, 2002; Widgren 2010). Weimarck (1968) noted that field terraces correlated with slash and burn cultivation in Sweden. In current study, field banks contained dispersed charcoal, but such accumulations were not found in the footslope trenches in forest sites (IV).

Large relict trees were present in 44 (93.6 %) former *buschlands* and were also found in 13 (31.7 %) former forest sites. The large trees in former *buschland*s are not probably remnants of slash and burn cultivation but would have started to grow after last cycle of slash and burn cultivation, when the abandoned fields were used for grazing. Only two relict trees with fire scars were found at the edge of former swidden in Paganamaa. In former forests, large relict trees could represent retention trees from the previous forest generation.

During the fieldwork, hollows of approximately 1–3 m diameter were found, mostly in the foothills. The locations and sizes of these hollows demonstrated that they are remnants of turnip pits. Similar turnip pits were observed in the Koli National Park, Finland (Tomson, 2007). Former turnip pits were observed in 13 former *buschland* sites (27.7 %) but were also observed in five forest sites (12.2 %). These pits are not good indicators of land use, because they may be dug in forest sites that were close to former fields, and turnips were not cultivated in every swidden. Therefore, the presence of turnip pits could provide only complementary information.

Clearance cairns that have been associated with slash and burn cultivation by different authors (Lang, 1995; Lageras and Bartholin, 2003; Lang, 2007) were present only in two sites. One of these sites was mapped as a forest site in the 19th century. Steep slopes of large hills have developed small gullies; these were observed in three former *buschland*s but were also observed outside of the studied sites.

Former rotational slash and burn patches are easy to recognise in hilly landscapes. In cultural landscapes in south-eastern Estonia, steep slopes are likely former swiddens and the typical landscape elements have confirmed that. In flat areas, the location in the periphery of villages is not a relevant indicator for the identification of former swiddens, because the transition to the forest is not traceable.

There was no identified vegetation species composition that was clearly characteristic of previous slash and burn cultivation areas that could be associated with effect of slash and burn cultivation. Therefore, the use of species composition does not serve as an indicator of former rotational swidden agriculture in Estonia.

The presence of soil charcoal did not serve as indicator of former slash and burn cultivation. Charcoal particles were not observed in three sites, two of which were former *buschland*s that had been used as arable field at the beginning of the 20th century, and one of which was a forest site. The estimated amount or character of charcoal particles were not found to be different between former *buschlands* and forests

Differences were found in the depths of soil charcoal; in former cultivated lands, the average depth tended to be deeper. However, these differences are not easy to use as an indicator of land use due to the high variability of charcoal locations. Charcoal could originate from different burnings; arable fields and former *bushlands* also contained charcoal from ancient wildfires that occurred prior to the beginning of cultivation, as demonstrated by the radiocarbon dating of charcoal from former *buschlands*. The best indicator of rotational slash and burn cultivation was the dispersed charcoal in the accumulated humus of field banks.

The extent of slash and burn cultivation was wider prior to the 19th century, as shown by the presence of field banks, but the results of the present study did not allow to determine the precise extent of slash and burn cultivation. It is especially difficult to determine the presence of ancient single slash and burn cultivation events. The restriction on the burning of old forests in the 17th century could have promoted the establishment of swiddens in remote places. Nonetheless, population numbers and the pollen diagrams (Poska et al., 2017) do not suggest that the extent of slash and burn cultivation was considerably larger than is depicted in 19th century maps. The elucidation of other human practises that used fire in forests, such as burning to create pastureland as has been observed in Sweden (Granström, 1996) or for apiculture (Linnus, 1936) will require future study.

CONCLUSIONS

Slash and burn cultivation has been an important factor in the formation of southern Estonian cultural landscapes. In Karula NP and Haanja NaP, 35 %–45 % of farmland was covered with *buschlands*, and large proportions of the landscape were overgrown with young trees of varying ages until the second part of the 19th century. Typical slash and burn cultivation areas were located in hilly landscapes. In flat areas, the swiddens were located at a greater distance from households than the permanent arable fields. Swiddens were located mostly on slopes and hilltops, and in moderately acidic soils; features that were similar to other European slash and burn cultivation areas. As in other Nordic European countries, the historical Estonian slash and burn cultivation areas were associated with moraines.

Buschlands became the type of land use unit that changed the most during the 20th century, with 78 % of them now covered by forests. This afforestation was the most rapid during World War II and continued in the Soviet era due to the mechanisation and intensification of agriculture. Afforestation was especially extensive in former *buschlands* due to their landscape characteristics. Former *buschland*s were the main source of secondary forests in south-eastern Estonia. In the present-day cultural landscape, former *buschlands* form a beautiful pattern of rounded hills with forest cover surrounded by open land. In more remote areas, former *buschlands* adjoin large historical forest blocks.

The most common types of forest now present in former *buschlands* are *Oxalis*, transitional *Oxalis-Vaccinium myrtillus*, and *Oxalis-Vaccinium vitis-idaea* forest subtypes. The *Hepatica* type was more common in younger forests that developed during the 20th century. The present-day vegetation in sites mapped as forests in the 19th century is different to that of former slash and burn sites, but the differences are not big. An analysis of the presence of plant species using perMANOVA showed significant differences between former *buschland*s and forests, but the variability accounted for 5.2 % of the total variation (p=0.004). Comparing the recent *buschlands*, older *buschlands*, and continuous forests the variability accounted for 4.1 % of the total variation. The effects of 20th century land use concealed 19th century land use, with a comparison of open versus transitional areas versus forests by perMANOVA accounting for

7.2 % of the total variability (p=0.002). Forest management has also resulted in the vegetation of former *buschlands* and forests vegetation to become more similar to each other. The results here showed that environmental conditions have been more important in the formation of ground vegetation than slash and burn cultivation, despite the selected forest stands being as uniform as possible. Rotational slash and burn cultivation may have increased the humus thickness and inhibited the formation of a litter layer, but no evidence was found that slash and burn cultivation had changed the soil pH permanently. No fire-prone species were found, and no differences were found in the presence of species sensitive to human impact. A direct effect by slash and burn cultivation was not proved, but some features suggested that in former slash and burn sites the typical forest vegetation has not yet entirely recovered, and that former slash and burn sites are similar to post-agricultural forests. The impoverishment of vegetation found in this study was not the result of soil damage, but indicated that the forest vegetation had not completely recolonised the sites after the cessation of cultivation. There was no proof that new forest types had been formed due to slash and burn cultivation.

Slash and burn cultivation has contributed to the charcoal stock of boreal forest soils, due to the wide extent of former swiddens. Charcoal was found in 97 % of sites with different land use histories, in both former *buschlands* and forests.

The causative factors influencing the depth of charcoal in the soil differed depending on land use history. The greatest average depth was found in former arable fields (40.6 cm); in former *buschlands* the average depth was 25.6 cm and in forests 19.9 cm. In recent wildfires and the experimental slash and burn fields, the charcoal was located near the surface, demonstrating that charcoal translocation in the soil took place. Burial of charcoal by tillage was revealed in both arable fields and former *buschlands*. The charcoal in arable fields and in former *buschland*s was not completely broken up during cultivation, so larger particles and agglomerates were found. The average maximal depth of the charcoal rich layer in *buschlands* was greater (16.6 cm) than could be explained by ploughing, probably due to soil fauna activity. Soil bioturbation before cultivation may have facilitated charcoal deposition, as revealed by radiocarbon dates from foothill trenches in former *buschland* sites (2126 calBC).

Any differences in the total quantity of soil charcoal in former slash and burn lands compared with permanent forest requires further studies, because only macroscopic charcoal was examined in the present study. Because of the large spatial and temporal variability of soil charcoal, the utilisation of soil charcoal as an indicator of former slash and burn cultivation is complicated. The best indicator appeared to be the presence of field banks, which contain accumulated humus with dispersed charcoal, but this type of feature is not found in flat areas and single cultivation events, and therefore additional methods needed to be developed. The simplest method would be to identify the areas used for rotational slash and burn cultivation using historical maps, but slash and burn cultivation may have had a wider extent than what is shown in maps.

The results corroborated the first hypothesis, showing that slash and burn cultivation was an important factor in the formation of southern Estonian cultural landscapes due to a wide extent in the 19th century. The results also confirmed the validity of the second part of this hypothesis, that the areas used for slash and burn cultivation have characteristic landscape features. Hilly landscape comprising *Albeluvisols* and *Haplic Albeluvisols* in moraines were typical of slash and burn cultivation areas. Most *bushlands* have experienced the same changes during the 20th century, to form the forest patches of the south-eastern Estonian cultural landscape. Characteristic landscape element such as large remnant trees, field banks, and turnip pits can still be found in these forests.

The hypothesis that regular slash and burn cultivation has had an effect on the formation of modern vegetation was not proven. The vegetation in former slash and burn sites and *buschland*s was to some extent different, but the effect of fire was not confirmed.

The hypothesis that slash and burn cultivation has contributed to the charcoal stock of boreal forest soils was confirmed, because charcoal was found in the soil profiles of former slash and burn sites. The slash and burn cultivation areas were of considerable extent and were larger than illustrated in the 19th century maps. This hypothesis also proposed that is possible to determine relevant indicators that can be utilised to identify the sites used for slash and burn cultivation; this was only partly proven because it was discovered that identification of former slash and burn sites was straightforward, but it was not so simple to identify continuous forest land.

This study fulfilled its main objective, which was to estimate the effects of historical slash and burn cultivation on the formation of southern Estonian cultural landscapes and forest vegetation. The results of the present study show that the role of slash and burn cultivation in the formation of the landscape has been important and underestimated, while the effect on the forest vegetation has been overestimated, and that the vegetation differences between former rotational slash and burn sites could be accounted for by delayed afforestation, rather than the effects of the use of fire for cultivation.

REFERENCES

Angelstam, P., Kuuluvainen, T. (2004). Boreal forest disturbance regimes, successional dynamics and landscape structures – a European perspective. Ecological Bulletins 51, 117–136.

Asi, E., Kõlli, R., Laas, E. (Eds.) (2004). E. Põllumajandusmaade metsastamine. Põllumaade metsastamise metoodiline juhend (Afforestation of Arable Land. Guidelines for afforestation of arable land). Metsakaitse- ja metsauuenduskeskus, Tartu, 83 pp. (In Estonian).

Astover, A., Kõlli, R., Roostalu, H., Reintam, E., Leedu, E. (2012). Mullateadus. Õpik kõrgkoolidele (Soil science. Textbook for Highschools). Eesti Maaülikool, Tartu, 486 pp. (In Estonian).

Astover, A., Reintam, E., Leedu, E., Kõlli, R. (2013). Muldade väliuurimine (Field Study of Soils). Eesti Maaülikool, Tartu. 70 pp. (In Estonian).

Axelsson, A.L., Östlund, L. (2001). Retrospective cap analyses in Swedish boreal forest landscape using historical data. Forest Ecology and Management 147, 109–122.

Berglund, B.E., Kitagawa, J., Lagerås, P. Nakamura K. Sasaki, N., Yasuda, Y. (2014). Traditional farming landscapes for sustainable living in Scandinavia and Japan: global revival through the Satoyama Initiative. Ambio, 43(5), 559–578.

Bobrovskii, M.V. (2010). Effect of the historical land use on the structure of forest soils in European Russia. European Soil Science, 43(13), 1458–1466.

Bobrovsky M. (Бобровский, М. В.) (2010). Лесные почвы Европейской России: биотические и антропогенные факторы формированиа (Forest soil of European Russia: biotic and anthropogenic factors in pedogenesis). KMK Scientific Press, 359 pp. (In Russian).

Bunce, R.G.H., Shaw, M.W. (1973). A standardised method for ecological survey. Journal of Environmental Management, 1, 239–258.

Certini, G. (2005). Effects of fire on properties of forest soils: a review. Oecologia, 143(1), 1–10.

Čugunovs, M., Tuittila, E.-S., Sara-Aho, I., Pekkola, L., Kouki, J. (2017). Recovery of boreal forest soil and tree stand characteristics a century after intensive slash-and-burn cultivation. Silva Fennica, 51(5), 1–19.

Delgado-Matas, C. (2004). Dynamics of nutrients in slash and burn agroforestry in Koli National Park. In Lovén, L. (Ed.), Tutkittu ja tuntematon Koli. Metsäntutkimuslaitoksen Tiedonantoja, pp. 29–46.

Database of archaeological and place-lore sites. Centre for Archaeological Research and Infrastructure, Institute of History and Archaeology, University of Tartu. https://register.muinas.ee/public.php. Accessed 10.Jan. 2018. Not public acess.

Dupouey, J.L., Dambrine, E., Laffite, J.D., Moares, C. (2002). Irreversible impact of past land use on forest soils and biodiversity. Ecology, 83(11), 2978–2984.

Eriksson, M O.G. (2008). Management of Natura 2000 habitats. 9070 Fennoscandian wooded pastures. European Commission. Retrieved from - http -//ec.europa.eu/environment/nature/natura2000/management/habitats/pdf/9070_Fennoscandian_wooded_pastures.pdf

Eriksson, S., Skånes, H., Hammera, M., Lönna, M. (2010). Current distribution of older and deciduous forests as legacies from historical use patterns in a Swedish boreal landscape (1725–2007). Forest Ecology and Management, 260, 1095–1103.

Environmental Board of Estonia, digital archive. Copy obtained 15.02.2007

Estonian Land Board. (2014a). Historical maps. Accessed 12.Oct.2014

Estonian Land Board. (2014b). Estonian Digital Basic Map. Accessed 12.Oct.2014

Estonian Land Board. (2014c). Soil Map. Accessed 12.Oct.2014

Etverk, I. (1974). Metsa õpitakse tundma ja kasutama (They learn about the forest and management). In: Valk, U., Eilart, J. (Eds.), Estonian Forests. Valgus, Tallinn, pp. 40−60. (In Estonian).

FMD. Metsaregister, https://register.metsad.ee/#/. Accessed 12.Oct.2014

Goldhammer, J. F., Bruce, M. (2004). The use of prescribed fire in the land management of Western and Baltic Europe: an overview. International Forest Fire News, 30, 2-13. http -//www.fire.uni-freiburg.de/iffn/iffn_30/01-IFFN-30-Europe.pdf. Accessed 12.Oct.2014

Gorbachev,V.N., Popova, E.P. (1996). Fires and soil formation.In: Goldammer, J.G., Furyaev, V (Eds). Fire in ecosystems of boreal Eurasia. Kluwer Academic Publisher, Dordrecht, pp 331–336.

Granström, A. (1996) Fire Ecology in Sweden and Future Use of Fire for Maintaining Biodiversity. In: Goldammer, J.G., Furyaev, V. (Eds.). Fire in ecosystems of boreal Eurasia. Kluwer Academic Publisher, Dordrecht, pp 445–452.

Granström, A. (2001). Fire Management for Biodiversity in the European Boreal Forest, Scandinavian Journal of Forest Research, 16:S3, 62-69.

Gromtsev, A. (2002). Natural disturbance dynamics in the boreal forests of European Russia: a review. Silva Fennica, 36, (1), 41–55.

Halshall, K.M., Ellingsen, V.M., Asplund, J., Bradshaw, R.H.W., Ohlson, M. (2018). Fossil charcoal quantification using manual and image analysis approaches. The Holocene, 1–9.

Hamilton, H. (1997). Slash and burn in the history of Swedish forests. Rural Development Forestry Network Paper, 21f, 19-24. http -// www.odi.org.uk/publications/754-slashburn-history-swedish-forests. Accessed 12.Oct.2014.

Heikinheimo, O. (1915). Kaskiviljelyksen vaikutus Suomen metsin (The impacts of slash and burn cultivation in the Finnish Forests). Metsähallituksen julkaisuja II. Keisarillisen senatiin kirjapainossa, Helsinki.136 pp. (In Finnish).

Hekkala, A-M., Tarvainen, O., Tolvanen, A. (2014). Dynamics of understory vegetation after restoration of natural characteristics in the boreal forests in Finland. Forest Ecology and Management, 330, 55–66.

Hellberg, E., Josefsson, T., Östlund, L. (2009). The transformation of a Norway spruce dominated landscape since pre-industrial times in northern Sweden: the influence of modern forest management on forest structure. Silva Fennica, 43(5), 783–797.

Hermy, M., Honnay, O., Firbank, L., Grashof-Bokdam, C., Lawesson, J.E. (1999). An ecological comparison between ancient and other forest plant species of Europe and the implication for forest conservation. Biological Conservation, 91, 9–22.

Hermy, M., Verheyen, K. (2007). Legacies of the past in the present-day forest biodiversity: a review of past land-use effects on forest plant species composition and diversity. Ecological Research, 22, 361–371.

Hokkanen, P. (2006). Environmental patterns and gradients in the vascular plants and bryophytes of eastern Fennoscandian herb-rich forests. Forest Ecology and Management, 229, 73–87.

Hoskins, W.G. (1970). The making of the English landscape. London, 325 pp.

Huttunen, P. (1980). Early land use, especially the slash and burn cultivation in the commune of Lammi, southern Finland, interpreted mainly using pollen and charcoal analysis. Acta Botanica Fennica, 113, 1–45.

Ingerpuu, N., Vellak, K. (Eds.), (1998). Eesti sammalde määraja (Keybook of Estonian Bryophytes). Eesti Loodusfoto, Tartu, 239 pp. (In Estonian).

Jääts, L., Kihno, K., Tomson, P., Konsa, M. (2010). Tracing fire cultivation in Estonia. Forestry Studies, 53, 53–65.

Jääts, L., Konsa, M., Kihno, K., Tomson, P. (2011). Fire Cultivation in Estonian Cultural Landscapes. The Space of Culture – the Place of Nature in Estonia and Beyond. (Approaches to Culture Theory; 1), Tartu Ülikooli Kirjastus, Tartu, pp 165−180.

Kivekäs, J., (1939). Kaskiviljelyksen vaikutus eräisiin maan ominaisuuksiin. Metsätieteellisen tutkimuslaitoksen (The impact of slash and burn cultivation to some soil property. Forestry study). Communicationes Instituti Forestalis Fenniae. 27, pp 1–44. (In Finnish).

Koppel, K. (2005). Maakasutuse uurimise metoodika Kasaritsa uurimisala (Rõuge kihelkond) 17.-19. sajandi külamaastike kujunemise näitel (The research methods of historical land use as exemplified by the formation of rural landscapes on Kasaritsa study area (Rõuge parish) in 17th–19th centuries). http://dspace.utlib.ee/dspace/handle/10062/1263. Accessed 12.Oct.2014. (In Estonian).

Kukk, T. (1999). Eesti taimestik (Vascular Plant Flora of Estonia). Estonian Academy of Science Press, Tartu-Tallinn, 464 p. (In Estonian).

Kuuluvainen, T., Aakala, T. (2011). Natural forest dynamics in boreal Fennoscandia: a review and classification. Silva Fennica, 45(5), 823–841.

Laasimer, L. (1958). Nõmmealade geobotaaniline iseloomustus ja areng Eestis. Nõmmealade taasmetsastamise ja nõmmemetsade majandamise küsimusi (The geobotanical characterization and development of oligotrophic sites in Estonian. The reforestation oligotrophic sites and management of oligotrophic forests). ZBI, Tartu, pp 29–43. (In Estonian)

Laasimer, L. (1965). Eesti NSV taimkate (The Vegetation of Estonian Soviet Socialist Republic). Valgus, Tallinn, 397 pp.

Lageårs, P., Bartholin, T. (2003). Fire and stone clearance in Iron Age agriculture: new insights inferred from the analysis of terrestrial macroscopic charcoal in clearance cairns in Hamneda, southern Sweden. Vegetation History and Archaeobotany, 12, 83–92.

Lankia, H., Wallenius, T., Várkonyi, G., Kouki, J., Snäll, T. (2012). Forest fire history, aspen and goatwillow in a Fennoscandian old-growth landscape: are current population structures a legacy of historical fires? Journal of Vegetation Science, 23, 1159–1169.

Lang, V. (1995) Prehistoric and medieval field systems in Estonia, Tools & Tillage, 7 (2–3), 67–82.

Lang, V. (2007). Muistsed maakasutussüsteemid Eestis. (Ancient land use systems in Estonia). Ajalooline Ajakiri, ¾: 291–320. http://ojs.utlib.ee/index.php/EAA/article/view/317/312. Accessed 19. Jan. 2018. (In Estonian)

Laul, S., Kihno, K. (1999). Prehistoric Land Use and Settlement History on the Haanja Heights, Southeastern Estonia, with Special Reference to the Siksali-Hino Area. – PACT, 57, 239–254.

Leht, M. (Ed.), (2010). Eesti taimede määraja (Keybook of Estonian plants). Eesti Loodusfoto, Tartu, 447 pp. (In Estonian).

Lehtonen, H. (1998). Fire history recorded on pine trunks and stumps: Influence of land use and fires on forest structure in North Karelia. Scandinavian Journal of Forest Research, 13 (1–4), 462–468.

Lehtonen, H., Huttunen, P. (1997). History of forest fires in eastern Finland from the fifteenth century AD – the possible effects of slash-and-burn cultivation. The Holocene, 7(2), 223–228.

Ligi, H. (1963). Põllumajanduslik maakasutus Eestis XVI–XVII sajandil (Agricultural land use in Estonia in XVI–XVII century). Tallinn, 137 pp. (In Estonian).

Liitoja-Tarkiainen, Ü. (2006). Talukõlvikud Vooremaal 17.–19. sajandil (Farmlands in Vooremaa in the 17th-19th centuries). In: Tamberg, T. (Ed). Vene aeg Eestis. Uurimusi 16. sajandi keskpaigast kuni 20. sajandi alguseni. Eesti Ajalooarhiivi Toimetised, 14(21), Tartu, pp 229−254. (In Estonian).

Liiwlandima Tallorahwa Säeduse-ramat. (1850). (Agrarian Law of the Livonian Governorate). Tartu. Schünmanni lesk ja C. Mattiesen, 282 pp. (In Southern Estonian).

Lindbladh, M., Axelsson, A-L., Hultberg, T., Brunet, J., Felton, A. (2014). From broadleaves to spruce – the borealization of southern Sweden. Scandinavian Journal of Forest Research, 29(7), 686–696.

Lindbladh, M., Bradshaw, R. (1998). The origin of present forest composition and pattern in Southern Sweden. Journal of Biogeography, 25(3), 463–477.

Linkola, M. (1987). Metsä kultuurimaisemana (Forest as a cultural landscape). Silva Fennica, 21(4), 362–373. (In Finnish).

Linnus, F. (1936). Baltimaade orduaegsest mesindusest. (The beekeeping in Order-time Baltic). Ajalooline ajakiri nr 1, 1–14. (In Estonian).

Livländisches Landraths-Collegium. (1885). Materialien zur Kenntniss der Livländischen Agrarverhältnisse mit Besonderer Berücksichtigung Der Knechts- und Tagelöhner-Bevölkerung. (Records about Livonian agricultural conditions with particular reference to servants and workers). Riga, 244 pp. (In German).

Lovén, L., Äänismaa, P. (2006). Kolin kaskiopas (The guide of slash and burn cultivation of Koli). 74 pp http://www.metla.fi/hanke/8025/pdf/kaskiopas.pdf. Accessed 15.April.2018. (In Finnish).

Lõhmus, E. (2004). Eesti metsakasvukohatüübid (Estonian Forest Site Types), second ed. Eesti Loodusfoto, Tartu, 80 pp. (In Estonian).

Maaranen, P. (2002). Human touch, natural processes: The development of the rural cultural landscape in southern Finland from past to present. Fennia, 180(1–2), 99–109. https://fennia.journal.fi/article/view/3769. Accessed 19. Jan. 2018.

Matuszkiewicz, J.M., Kowalska, A., Kozłowska, A, Roo-Zielińska, E., Solon, J. (2013). Differences in plant-species composition, richness and community structure in ancient and post-agricultural pine forests in central Poland. Forest Ecology and Management, 310, 567–576.

Meikar, T., Uri, V. (2000). Võsamaade majandamisest Eestis (Of the management of bushland in Estonia). In: Meikar, T., Etverk, I. (Eds.), Proceedings of the Academic Forestry Society, XI. Estonian forests and forestry at the turn of the Millennium. Tartu, pp. 103–120. (In Estonian).

Merila-Lattik, H. (2005.) Karm ja kaunis Karula. Elust, olust ja inimestest muinasajast tänapäevani (Rough and beautiful Karula. The peoples and way of life from ancient times to the present day). Eesti Folkloori Instituut, Tartu, 379 pp. (In Estonian).

Myllyntaus, T., Hares, M., Kunnas, J. (2002). Sustainability in danger? Slash-and-Burn cultivation in Nineteenth-century Finland and Twentieth-Century Southeast Asia. Environmental History, 7(2), 267–302.

Myllyntaus T., Mattila T. (2002) Decline or increase? The standing timber stock in Finland, 1800–1997. Ecological Economics, 41, 271–288.

Oldén, A., Komonen, A., Tervonen, K., Halme, P. (2017). Grazing and abandonment determine different tree dynamics in wood-pastures. Ambio, 46(2), 227–236.

Östlund, L., Zackrisson, O., Axelsson, A.-L. (1997). The history and transformation of a Scandinavian boreal forest landscape since the 19th century. Canadian Journal of Forest research, 27, 1198–1206.

Paal, J. (1997). Eesti kasvukohatüüpide klassifikatsioon. Classification of the Estonian vegetation site types. Tallinn, 200 pp. (In Estonian).

Paal, J., Turb, M., Köster, T., Rajandu, E., Liira, J. (2011). Forest land-use history affects the species composition and soil properties of old-aged hillock forests in Estonia. Journal of Forest Research, 16, 244–252.

Parviainen, J. (1996). Impact of fire on Finnish forest in past and today. Silva Fennica, 30 (2–3), 353–359.

Pluchon, N., Vincent, A.G., Gundale, M.J., Nilsson, M-C., Kardol, P., Wardle, D.A. (2016). The impact of charcoal and soil mixtures on decomposition and soil microbial communities in boreal forest. Applied Soil Ecology, 99, 40–50.

Poska, A., Väli, V., Kama, P., Tomson, P., Vassiljev, J., Kihno, K. (2017). Karula kõrgustiku taimkatte ning inimasustuse pärastjääaegne areng (The postglacial history of vegetation and land use dynamics in Karula

Upland). In: Järvet, A. (Ed.), Yearbook of the Estonian Geographical Society, vol. 42. Vali Press OÜ, Tallinn, pp. 25−43. (In Estonian).

Ponomarenko, E., Ershova, E., Tomson, P., Bakumenko, V.A. (2018). Multi-proxy analysis of sandy soils in historical slash-and-burn sites: Karula case study. Quaternary International. (In Press).

Pyne, S.J., Andrews, P.L., Laven, R.D. (1996). Introduction to wildland fire. John Wiley, New York, 772 pp.

Raet, J., Sepp, K., Kaasik, A. (2008). Assessment of changes in forest cover-age based in historical maps. Forestry Studies, 48, 67–78.

Reintam, L., Moora, T. (Рейнтам, Л.Ю, Моора Т.Х.) (1983). О влянии подсечного земледелия на свойства почв. (The impact of slash and burn cultivation to the soil properties). В кн: Человек растительность и почва. АН ЭССР, Тарту, pp .145−153. (In Russian).

Rõuk, A.-M. (1995). Inimtegevus ja selle mõju loodusele (Human impact on nature). In: Raukas, A. (Ed.), Eesti Loodus. Valgus and Eesti Entsüklopeediakirjastus, Tallinn, pp. 494−517. (In Estonian).

Ruokalainen, L., Salo, K. (2009). The effect of fire intebiognsity on vegetation succession on a sub-xeric heath during ten years after wildfire. Annales Botanici Fennici, 46, 30–42.

Sarmela, M. (1987). Swidden Cultivation in Finland as a Cultural System. Suomen antropologi – Finnish Anthropologist, 4, 241–262.

Scott, A.C. (2010). Charcoal recognition, taphonomy and uses in palaeoenvironmental analysis. Palaeogeography, Palaeoclimatology, Palaeoecology, 291, 11–39.

Sigaut, F. (1979). Swidden cultivation in Europe. A question for tropical anthropologists. Social Science Information, 18 (4–5), 679–694.

Schimmel, J., Granstrom, A. (1996). Fire severity and vegetation response in the boreal Swedish forest. Ecology, 77(5), 1436–1450.

Schoch, W., Heller, I., Schweingruber, F.H., Kienast, F. (2004). Wood anatomy of central European Species. Online version: www.woodanatomy.ch. Accessed 15.Nov.2017.

Sepp, T., Liira, J. (2009). Vanade salumetsade rohurinde koosseis ja seda mõjutavad tegurid (Factors influencing the species composition and richness of herb layer in old boreo-nemoral forests). Forestry Studies, 50, 23–41. (In Estonina with English Summary).

Soininen, A.M. (1959). Burn-beating as the technical basis of colonisation in Finland in the 16th and 17th centuries. Scandinavian Economic History Review, 7(2), 150–166.

Zobel, K., Zobel, M., Peet, R.K. (1993). Change in pattern diversity during secondary succession in Estonian forests. Journal of Vegetation Science, 4, 489–498.

Tarand, A., Jaagus, J., Kallis. A. (2013). Eesti kliima minevikus ja tänapäeval (Estonian climate in past and present). University of Tartu Press, Tartu, pp 632. (In Estonian).

Tarkiainen, Ü. (2008). Rural Property, Inheritance, and the Modernization of the Estonian Agrarian Sector 1880-1914. In: Wawrzeniuk, P. (Ed.). Societal Change and ideological Formation among the Rural Population of the Baltic Area 1880-1939 (121−139). Huddinge: Södertörns Högskola. (Studia Baltica; II:2).

Tarkiainen, Ü. (2014). Aletamine maastikukujunduse- ja kultuuritegurina Põhja-Euroopas ja Eestis (Slash and burn cultivation as factor of landscape design and culture in Northern Europe and in Estonia). Tuna. Ajalookultuuri ajakiri, 1, 26–41. (In Estonian).

Tomson, P. (2007). Tutvus punase kolmnurgaga. Eesti Loodus, 4. http://www.eestiloodus.ee/artikkel1875_1872.html Accessed 14.Jan.2018. (In Estonian).

Tollin, C. (2017). How to identify areas that have been used as kaski-swidden-land before 1800. Method: large scale geometrical maps. Building Bridges. Abstract book of the 23rd Annual Meeting of the European Association of Archaeologists 2017, pp 374. http://www.eaa2017maastricht.nl/. Accessed 13.Apr.2018.

Uotila, A., Kouki, J., Kontkanen, H., Pulkkinen, P. (2002.) Assessing the naturalness of eastern Fennoscandian boreal forests. Forest Ecology and Management, 161, 257–277.

Vabariigi digitaalse suuremõõtkavalise mullastiku kaardi seletuskiri. (2001). (Headnotes of digital large scale soil map of Estonia). Maa-amet, Tallinn. http://www.maaamet.ee/docs/kaardid/mullakaardi_seletuskiri.pdf. Accessed 25.Oct. 2014

Vanha-Majamaa, I., Lilja, S., Ryömä, R., Kotiaho, J. S., Laaka-Lindberg, S., Lindberg, H., Puttonen, P., Tamminen, P., Toivanen, T., Kuuluvainen, T. (2007). Rehabilitating boreal forest structure and species composition in Finland through logging, dead wood creation and fire: the EVO experiment. Forest Ecology and Management, 250(1-2), 77-88.

Vasari, Y. (1992). Kasvitieteellinen ja stratigrafinen näkokulma Suomen ympäristö-historiaan (The botanical and stratigraphic point of view in Finnish environment history). Huhta, V. (Ed). Suomen muutuva luonto. Mikko Raatikaiselle omistettu juhlakirja. Jyvaskylan Yliopistu, Jyvaskyla, pp.155–163. (In Finnish).

Verheyen, K., Guntenspergen, G.R., Biesbrouck, B., Hermy, M. (2003). An integrated analysis of the effects of past land use on forest herb colonization at the landscape. Journal of Ecology, 91, 731–742.

Viro, P.J. (1974). Effects of forest fire on soil. In: Kozlowski, T.T., Ahlgren, C.E. (Eds.), Fire and ecosystems. New York, pp. 7–45.

Voionmaa, V. (1987). History of the Karelian Tribe in Finland-Extracts. Suomen Antropology, 4, 207–212.

Wallenius, T. (2002). Forest age distribution and traces of past fires in a natural boreal landscape dominated by Picea abies. Silva Fennica, 36(1), 201–211.

Wallenius, T. (2011). Major decline in fires in coniferous forests – Reconstructing the phenomenon and seeking for the cause. Silva Fennica, 45(1), 139–155.

Weimarck, G. (1968). Ulfshult: investigations concerning the use of soil and forest in Ulfshult, parish of Örkened, during the last 250 years. Ulfshult at the 1717 and 1747 surveys by Gunhild Weimarck. C.W.K. Gleerup, Lund. 66 pp.

Widgren, M. (2010). Reading the prehistoric landscape. Ymer 130: 69–85 http://pcwww.liv.ac.uk/~easouti/methodology_application.htm. Accessed 19.Jan.2018.

Wulf, M. (1997). Plant species as indicators of ancient woodland in northwestern Germany. Journal of Vegetation Science, 8, 635–642.

Wulf, M. (2003). Preference of plant species for woodlands with differing habitat continuities. Flora, 198, 444–460.

Wulf, M. (2004). Plant species richness of afforestation with different former use and habitat continuity. Forest Ecolgy and Management, 195, 191–204.

Zackrisson, O. (1977). Influence of Forest Fires on the North Swedish Boreal Forest. Oikos, 29(1), 22–32.

SUMMARY IN ESTONIAN

Ajaloolise alepõllunduse roll Lõuna-Eesti maastike ja metsataimestiku kujunemisel

Regulaarne alepõletamine oli Põhja- ja Kesk-Euroopas levinud kuni 19. sajandi lõpuni, kohati kauemgi. Teaduslikke uuringuid alepõletamise kohta Euroopas on aga tänini ilmunud vähe. 20. sajandi algupoolel on alepõllundusest küll kirjutatud, kuid nende allikate kasutamist raskendab asjaolu, et need olid vene, soome, rootsi ja saksa keeles. Tänapäevast ingliskeelset teaduskirjandust on Euroopas toimunud aletamise mõjude kohta raske leida. Kõige rohkem on aletamise mõjusid käsitletud Soomes, kus on kirjeldatud endistele alepõldudele kujunenud niite ja puiskarjamaid ning rohundirikkaid metsi. Soomes on alepõletamist kasutatud kooslusi taastava võttena (Lovén ja Äänismaa, 2006).

Eestis on alepõletamisega seonduvat käsitlenud peamiselt ajaloolased (nt Ligi, 1963; Jääts jt 2010; Tarkiainen 2014). Loodusteadlased on aletamise mõjusid nimetatud enamasti vaid põgusalt muude teemade kõrval. Reintam ja Moora (1983) on väitnud, et aletamine soodustab muldade leetumist. Laasimer (1958) tõi aletamise mõjuna esile muldade väljakurnamise ja sellega seotud taimestiku vaesumise ja liigivaeste metsakoosluste, eelkõige kuivade männikute, kujunemise.

Käesolev uurimistöö lähtub teadmisest, et Eestis kasutati alepõletamist maaharimisvõttena kuni 19. sajandi lõpuni, ning eeldusest, et 19. sajandi Liivimaa kubermangus koostatud maakasutuse kaardid võimaldavad täpsemalt uurida regulaarse aletamise ulatust ja mõjusid. Neil kaartidel ja dokumentides on regulaarselt aletatavaid alasid nimetatud spetsiaalse balti-saksa terminiga *buschland*. Sama perioodi eestikeelsetes allikates nimetati seda metsamaaks. Tänapäevases teaduskirjanduses on kasutatud terminit võsamaa (Ligi, 1963, Meikar ja Uri 2000).

Käesoleva töö eesmärk oli välja selgitada 19. sajandi regulaarse aletamise mõju Lõuna-Eesti maastikele ja metsakooslustele. Mõju hindamine jagati järgmisteks uurimisülesanneteks:

– hinnata regulaarse aletamise ulatust 19. sajandil ja kirjeldada korduvaks aletamiseks kasutatud alade tunnuseid;

– teha kindlaks, kuidas on endiste aletatud alade maakate 20. sajandi jooksul muutunud;
– teha kindlaks regulaarse aletamise mõju metsataimestikule;
– kirjeldada regulaarse aletamise mõju mullas leiduvate söeosakeste hulgale ja paiknemisele ning leida meetodid, mille abil saab aleviljeluseks kasutatud alasid kindlaks teha.

Uurimisküsimustele vastuste saamiseks püsitati järgmised hüpoteesid:

– regulaarne aletamine on olnud Lõuna-Eesti kultuurmaastike kujunemisel oluline tegur;
– aletatamiseks kasutatud aladel on iseloomulikud tunnused;
– aletamine on mõjutanud tänapäevase taimkatte kujunemist aletatud kohtades;
– aletamisel on olnud oluline roll metsamuldades leiduva söe tekkimises;
– aleviljeluseks kasutatud alade kindlakstegemiseks on võimalik leida sobivad meetodid.

Uurimisalad paiknevad Kagu-Eestis: Karula rahvuspargis, Haanja looduspargis, Karula Pikkjärve ja Paganamaa maastikukaitsealadel ning Pähni ja Mõisamõtsa looduskaitsealadel. Töö aluseks võeti 61 aastatel 1851–1900 koostatud maakasutuskaarti, millel on *buschland* tähistatud.

Töö esimeses etapis teostati kaardianalüüs, mille jaoks georefereeriti ja digiteeriti 51 19. sajandi talukaarti ja Saaluse mõisa talumaade kruntimiskaart. Aletatud alade iseloomulike tunnuste leidmiseks kasutati võrdluseks digitaalset mullakaarti ja Metsaregistrit. 20. sajandil toimunud muutuste uurimiseks võrreldi 19. sajandi digiteeritud talukaarte ajalooliste kaartidega 20. sajandist (1-verstane kaart, NSVL topograafiline kaart 1950ndatest, katastrikaart 1980ndatest) ja Eesti põhikaardiga.

Teises etapis teostati kunagistel aletatud aladel taimkatte uurimiseks välitööd Bunce ja Shaw (1973) metoodikat järgides. Võsamaade võrdluseks valiti jäneskapsa kasvukohatüüpi metsad aladel, mis olid 19. sajandil kaardistatud metsamaana, neid nimetatakse edaspidi järjepidevateks metsadeks. Jänesekapsa kasvukohatüüp oli eelneva analüüsi põhjal osutunud kunagistel alemaadel kõige levinumaks. Uuringuks valiti 80 eraldist (45 endisel võsamaal ja 35 järjepidevas metsas), kus peapuuliik oli rohkem kui 90-aastane ja mis olid võimalikult väikese metsamajandamise mõjuga. Uuringute käigus teostati ka mullakaeve, koguti proovid laboratoorseteks analüüsideks ja hinnati makroskoopilise (nähtava) söe iseloomu ning hulka kaeves.

Mullasöe hulga, paiknemise ja vanuse täpsemaks määramiseks tehti kokku 106 mullakaevet, mis asusid erineva maakasutusajalooga aladel: 19. sajandi põlispõldudel, järjepideval metsamaal, võsamaal ning hiljutiste metsapõlengute ja eksperimentaalse alepõllu aladel. Rajati kuus tranšeed küngaste jalamile. Kokku dateeriti 20 söeproovi ja määrati 355 söetüki puidu liik.

Taimkatte ja mulla andmestike statistilisel analüüsil kasutati järgmiseid meetodeid: peakomponentanalüüs, ühe- ja mitmemõõtmeline mitteparameetriline dispersioonanalüüs permutatsioonimeetodil ning varieeruvuse komponentideks jagamise analüüs. Analüüsid viidi läbi statistikaprogrammi R abil.

Töö tulemusel selgus, et regulaarselt aletatud alad olid laialt levinud, kattes 35–45%. analüüsitud talumaadest. Saadud tulemus on suurem 1881/83 põllumajandusrevisjonis (Livländisches Landraths-Collegium, 1885) revisjonis Karula ja Rõuge kihelkonna kohta toodud arvudest, kuid arvestada tuleb, et uurimisalad paiknesid vastavate kihelkondade kõige künklikumates piirkondades. Uurimistulemused näitavad, et Kagu-Eesti kõrgustikel oli *buschland* enamasti seotud küngaste ja nõlvadega. Tasasematel aladel aga asusid võsamaad talust kaugemal metsamassiivi serval. Aleviljeluse seos künkliku või mägise reljeefiga on jälgitav ka mujal Euroopas (Sigaut, 1979). Iseloomulikud võsamaade mullad on näivleetunud ja leetunud mullad. Eestis, nii nagu ka naabermaades Rootsis ja Soomes, on aletamine seotud moreenide levikuga.

19. sajandi maakasutuskaartidel märgitud *buschland* oli iseseisev spetsiifilise kasutuse ja muutuva maakattega maakategooria, mida ei saa paigutada ühegi tänapäeval tuntud maakatte- ega maakasutusklassi alla. Maastikel oli tollal mitmesuguses taastumisastmes võsaseid alasid, mis 20. sajandil maastikupildist kadusid – kõlvikud muutusid täpsemalt määratletava maakattega üksusteks ning maastikupilt selgemalt piiritletavaks.

20. sajandi alguses muudeti enamus endistest alemaadest põllumaaks; 20. sajandi lõpuks aga suurem osa (78%) metsastus. Metsastumise tõus

oli suurim Teise maailmasõja aegsel kümnendil, ilmselt küüditamise ja sõjategevuse tagajärjel. Metsastumine jätkus nõukogude ajal mehhaniseerimise ja põldude massiivistamise tõttu, sest järsud kallakud ei sobinud masinatega harimiseks. Selle tulemusena jäeti väikesed ja kaugel asuvad põllutükid kasutusest välja. Endised alemaad on 20. sajandi jooksul kõige enam muutusi läbi teinud maakategooria ja need moodustavad talumaadele kasvanud sekundaarsetest metsadest kõige suurema osa. Alemaade metsastumise tõttu on kujunenud Kagu-Eestile iseloomulik metsastunud kuplitega kultuurmaastik.

Buschland'i ja metsade taimkatte võrdlemisel selgus statistiliselt usaldusväärne erinevus 24 liigi esinemissageduse puhul. Sellest suure rühma moodustasid noored lehtpuud, mida aletatud aladel leidus sagedamini. Põhjuseks võib olla, et taastumisjärgus alemaadel olid levinud lehtpuud ja need liigid on jäänud endistel alemaadel püsima. Tõenäolisem on, et kuna aletatud alad on rohkem kultuurmaastikega seotud ja lähemal avatud metsaservadele, levivad valgusnõudlikud liigid seal lihtsamini. Puuliikidest domineerib mõlemat tüüpi metsades ülarindes mänd, vähem kuusk. Alusmetsas on kõikjal levinud kuusk.

Rohurinde liikidest leiti erinevusi 17 liigi esinemise osas ja 19 liigi katvuse osas, kuid erinevused ei viita konkreetsele keskkonnamõjule. Järjepidevas metsas sagedamini esinenud liigid ei seostu alati metsa püsivusega, näiteks leidus 19. sajandi metsamaal rohkem metskastikut (*Calamagrostis arundinacea*), mille levikut soodustab metsamajandus, sagedamini leidus ka maikellukest (*Convallaria majalis*), mida võib kohata ka poolavatud kasvukohtades, näiteks loopealsetel. Aletatud aladel esines sagedamini maasikat. Soomest on teada, et metsmaasikas levib karjamaadel, mis on kujunenud mahajäetud alepõldudele. Järjepidevates metsades oli suurem keskmine katvus pohlal ja laiuval sõnajalal, neist esimene oli enam levinud Karula kuivematel ja väheviljakates metsades ja teine Haanja viljakatel metsamaadel. Võsamaade ja järjepidevate metsade võrdlemisel ei leitud erineva inimmõju taluvusega liikide ega vanade metsade indikaatorliikide (Wulff, 2003 järgi) keskmise arvus. Endisetel alemaadel esines keskmiselt vähem sipelgate abil levivaid liike, mis näitab, et aeglase levikuga liigid ei ole veel igale poole jõudnud. 20. sajandi alguse maakate (st kas vaadeldavad alad olid siis veel lagedad, põõsastikud ja harvikud või kaetud metsaga) mõjutas taimestikku enam kui 19. sajandi maakasutus. Mulla reakstiooni ning lämmastiku- ja süsinikusisalduse erinevus metsaaladel ja aletatud aladel osutus statistiliselt ebaoluliseks. Küll tuvastati, et aletatud aladele on iseloomulik õhem varisekiht ja paksem huumuskiht. Varisekiht vajab peale põllumaana kasutust aega taastumiseks. Huumuskihi kujunemist on tõenäoliselt mõjutanud aletatud alade kündmine ja ka see, et alemaad olid puhkefaasis kaetud alguses rohttaimestikuga ning seejärel lehtpuuvõsaga. Lehtmetsade ja rohumaade mullaelustik ja mullatekkeprotsessid on erinevad okasmetsade omast ning soodustavad huumuse teket.

Uuringu tulemusel ei leitud tulelembeseid ega muutunud mullastikutingimusi näitavaid liike ja taimkattemustrit, mis näitab, et tule kasutamine ei ole kasvutingimusi jäädavalt mõjutanud. Seega tuleb aletatud aladele kasvanud metsi pidada pigem sarnaseks endistele põllumajandusmaadele kasvanud vaesunud koosseisuga sekundaarsete metsadega, mitte pool-looduslikeks kooslusteks, mis vajavad säilitamiseks spetsiifilist majandamist.

Pea kõikjalt uuritud aladelt (97%) leiti mullast makroskoopilist sütt. Kuivõrd aletatud alad on kunagistel kultuurmaastikel laialt levinud, on aletamise tähtsus regiooni mulla söesisalduse kujunemisel olnud suur. Söe sügavusega seotud näitajad (keskmine maksimaalne ja minimaalne sügavus ning söerikka kihi keskmine maksimaalne ja minimaalne sügavus) olid maakasutse ajalooga seotud, hinnatav söe hulk ning selle iseloom aga mitte. Kui söekihi mõõdetud suurima sügavuse keskmine oli 19. sajandi põlispõldudel 40,6 cm, siis endistel alemaadel 25,6 cm, ja metsades 19,9 cm. Söe sügavust tuleks vaadelda mineraalmulla suhtes, sest see kajastab söe algset asukohta pärast põlengut ega sõltu varise moodustumisest. Hiljutiste metsapõlengute alal ja eksperimentaalsetel alepõldudel asus süsi kõige kõrgemal, mis näitab, et sügavamale mulda satub see aja jooksul. Seega on mullasöe analüüsil oluline arvestada ka protsesse, mille tulemusena süsi mullas ümber paikneb. Aletamise puhul on selleks eeldatavasti mullaharimine. Kuivõrd söerikka kihi sügavus mineraalmulla suhtes oli keskmiselt suurem, kui võiks eeldada traditsiooniliste maaharimisriistade kasutamisel (5–10 cm versus 16,6 cm), siis tuleb arvestada ka muude protsessidega, eelkõige peamiselt huumuskihis tegutsevate endogeiliste vihmausside ja muu mullafauna tegevusega. Metsapõlengute puhul peetakse söe mattumise peamiseks põhjuseks pinnase ümberpaiknemist, mis toimub puude murdumisel koos juuremättaga. Söe peenema fraktsiooni segunemises mullaga on roll ka pinnase külmumisel ning sulamisel ja juurte mõjul. 19 sajandi põlispõldudelt leitud süsi pärineb nende eelnevast kasutamisest alemaana, põllu raadamisest või enne põllu raadamist toimunud metsapõlengutest.

Aletatud nõlvadel kogunes maaharimisega kaasneva erosiooni tõttu nõlva jalamile künniperv, mis koosnes põhiliselt hajutatud sütt sisalduvast huumusest. Intensiivse metsapõlengu puhul moodustub küll mäe jalamile põhiliselt mikroskoopilisest söest koosnev tume kiht, kuid mitte perve

Kõigist puuliikidest leiti kõige rohkem männi sütt, mis oli enam levinud nii endistel alemaadel kui metsades. Kuusk oli levinum endistel põlispõldudel. Eeldatust vähem leiti alemaadelt kase ja lepa sütt. Metsapõlengualalt leiti rohkem mittepuidulist sütt, mis seostub madala intensiivsusega pinnatulega.

Alemaadelt huumuskihist leitud süsi dateeriti vahemikku 1566–1805 calAD, mis sobib kirjanduses toodud andmetega regulaarse aletamise aja kohta. Künnipervedes paiknes lisaks huumuskihile süsi rohkem või vähem selgete kihtidena ka sügavamal. Kui hajusamad mineraalmullaga segatud üleminekulised söerikkad kihid võivad olla dateeringute kohaselt seotud maa esmase kasutuselevõtuga, siis sügavamad kihid näitavad looduslikke põlenguid. Võrdlus lähedal paiknenud asulakohtade vanusega arheoloogilise leiumaterjali alusel aitab söekihtide päritolu tõlgendada. Piirkonna senised arheoloogilised ja palünoloogilised uuringud viitavad, et põlengud, mis on dateeritud aega ligi 2000 aastat enne Kristust, ei ole olnud seotud põllundusega. Vanim antud uuringu käigus leitud sütest dateeriti aega 3731 calBC. Tranšeedes tehtud dateeringud näitavad, et künnipervedes on söe vanus ja sügavus enamasti omavahel seotud. Seega võib ühes kohas leiduda eri aegade põlengute sütt. Välistada ei saa ka metsapõlengute ja alesüte omavahelist segunemist mullasiseste ümberpaiknemiste tõttu.

Uuringutulemused näitavad, et 19. sajandil aletatud alasid on lihtsam kindlaks teha kui järjepidevaid metsi. Aletusalade tuvastamiseks sobivad ajaloolised maakasutuskaardid ning künklikul maastikul ka künnipervede olemasolu. Tasastel aladel nii selget maastikulist tunnust ei leidu ja asustusest kaugemal asuvate alemaade puhul võib üleminek endiselt alepõllult järjepidevale metsamaale jääda maastikus märkamatuks. Aletatud aladele spetsiifilist taimeliikide koosseisu ega üksikuid iseloomulikke liike leida ei õnnestunud, seega taimestikku indikaatorina kasutada ei saa. Ka ei kanna infot varasema maakasutuse kohta makroskoopilise söe leidumine mullas ega selle visuaalselt hinnatav hulk kaeves. Kuigi sütt sisaldava kihi keskmine sügavus mullas osutus aletatud aladel ja metsades erinevaks, ei sobi ka see endise maakasutuse kindlakstegemiseks välitöö tingimustes, sest tegemist on statistilise erinevusega ning söe paiknemise varieeruvus sama maakasutuse kategooria sees on suur.

Töö tulemused kinnitasid hüpoteesi, et regulaarne aletamine on olnud oluline tegur Lõuna-Eesti kultuurmaastike kujunemisel. Leidis kinnitust, et regulaarseks aletamiseks kasutatud maadel on iseloomulikud tunnused nagu muudest kõlvikutest suurem kaugus talukeskusest, laiem levik künklikul maastikul ja keskmise viljakusega happeliste muldade domineerimine. Seos kallakutega ja moreenidel kujunenud muldadega on sarnaned Soome ja Norra alemaadele.

Kinnitust ei leidnud hüpotees, et aletamine on mõjutanud tänapäevase taimkatte kujunemist. Ehkki tõestati taimkatte erinevused 19. sajandil võsamaadena ja metsadena kaardistatud alade taimkattes, viitas erinevuste iseloom pigem sellele, et need on tingitud aletatud alade hilisemast metsastumisest, mitte tule kasutamisest. Kinnitust leidis hüpotees, et aletamisel on olnud oluline roll metsamuldades leiduva söe kujunemisele: sütt leidus peaaegu kõikide proovikohtade muldades. Dateeringud ja põlluperved näitasid, et endiste võsamaade mullas on alepõletamise tagajärjel tekkinud hajusalt paiknevat süsi sisaldav huumuskiht. Hüpoteesi, et aleviljeluseks kasutatud alade kindlakstegemiseks on võimalik leida sobivad meetodid, õnnetus antud töö käigus tõestada vaid osaliselt. Kui viimaste sajandite alepõletamist on võimalik kindlaks teha ajalooliste kaartide alusel ja künklikul maastikul ka künnipervede järgi, siis varasema üksiku aletamise ja metsapõlengu jälgede eristamiseks on vaja leida veel täiendavaid indikaatoreid.

Kokkuvõtlikult selgus töö tulemusena, et aletamine on toimunud laialdasemalt, kui on märgitud 19. sajandi kaartidel. Kuna suurem rahvastiku juurekasv leidis aset alates 18. sajandi lõpust, ei ole alust arvata, nagu oleks varem toimunud intensiivne aletamine laiadel aladel; seda ei näita ka õietolmuandmed. Samuti ei ole alust eeldusel, nagu oleksid varasema aletamise mõjud keskkonnale olnud suuremad kui 19. sajandi lühikese tsükliga ale puhul. Käeolev töö näitab, et maastike uurimisel on aletamise mõju seni alahinnatud, taimestiku ajaloo kirjeldamisel aga pigem ülehinnatud.

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Research Paper

The role of slash and burn cultivation in the formation of southern Estonian landscapes and implications for nature conservation

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HIGHLIGHTS

- Fire cultivation played an important role in the formation of the patterns in rural landscapes in Southern Estonia.
- The former slash and burn areas have been the most changeable areas as shown in the study of Nineteenth Century maps.
- The former slash and burn areas are identifiable in the present landscape and are mainly transformed into forest.
- Knowledge of the historical significance of slash and burn is essential for the development of policies for nature conservation.
- The impacts of fire cultivation on the forest habitats need future study.

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ABSTRACT

Cultural landscapes result from the application of traditional management practices usually over centuries and are amongst the most valued in Europe. However, their composition is widely threatened by modern agriculture. It is therefore necessary to understand the historical factors involved in their formation, so that appropriate policies can be developed for maintaining their character. The present paper assesses for the first time the importance of slash and burn cultivation in the formation of current landscape patterns in Southern Estonia. Although generally associated with the tropics, this practice commenced in the Baltic region in the Bronze Age and persisted until the beginning of the Twentieth Century. The historical background to the practice is given and a detailed study is then described from Karula National Park in Southern Estonia. Parcels of different land covers were digitized from 51 farm maps for five dates from the 1860–1870's to the present day in order to record the changes. In the mid Nineteenth Century slash and burn parcels covered 35% of the farms lands. Because of the hilly relief 79% of the parcels have returned to forest during the Twentieth Century. The comparable changes are characteristic of other upland areas in Southern Estonia. The management policy in the Park needs to take into account the role of slash and burn in the formation of these areas of forest and their contribution to the modern landscape structure. The contribution to biodiversity of the secondary forests in the former slash and burn areas needs future study.

1. Introduction

Cultural landscapes involving traditional practices and a long history of management are amongst the most valuable in Europe, emphasized by Pedroli et al, 2007. The long-term durability of extensive agriculture has often created diverse patterns in these landscapes. In order to maintain and conserve this landscape heritage, it is necessary to understand their character and the changes that have taken place, so that appropriate management methods can be supported.

European rural landscapes have undergone major changes through historical times and the development of European landscapes can be divided into three periods, as described by Antrop (2005). Firstly, traditional landscapes were formed gradually by human labour, mainly in agriculture, until the end of Eighteenth Century. From the Nineteenth until the mid-Twentieth Century a second period can be identified, characterized by the major expansion of urbanized landscapes, development of new agricultural techniques and demographic growth. These processes caused rapid changes in landscape patterns. The third phase started after the Second World War and may be described as the post-modern period.

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The transformation of many rural landscapes in the Twentieth Century was connected with increased urbanization but also with the mechanization and intensification of agriculture and the abandonment of remote and less productive land. The changes in Estonian cultural landscapes in the middle of the Twentieth Century were similar to the transition of modern landscapes elsewhere in Western Europe. However, in Eastern Europe it is also necessary to consider different political developments, which have also left their imprint on the landscape (Palang, Spek, & Stenseke, 2011). The land reforms which changed the land use patterns, occurred three times in Estonia in the Twentieth Century. In Estonia therefore, the abandonment of isolated farmhouses and more remote agricultural land was more widespread than in the West, due to Soviet collectivization. As a result, during the Twentieth Century forest cover in Estonia increased from 14% to 42%, whereas agricultural land decreased from 65% to 30% (Palang, Mander, & Luud, 1998).

Landscape changes in the Nineteenth Century have not been the focus of studies in Estonia. There are some mostly methodological studies (Koppa, 2005, 2006; Raet, Sepp, & Kaasik, 2008Veski, Koppel, & Poska, 2005). These studies contain some information on Nineteenth Century land use and land cover, but this is not the main objective of these papers. The changing social and political processes of the Nineteenth Century are well described by historians (Kahk, 1992) but their impacts on landscapes have not received the same attention. Also, in this Century, land property rights changed. Historically, the land was the property of German speaking landlords from the Middle Ages until the Nineteenth Century, when the peasants were emancipated. Subsequently they rented the land, until land purchase started in the second part of the Nineteenth Century (Maandi, 2010).

During the pre-industrial period, open fields formed the prevalent agricultural system in Estonia. The classic features of the open field system were individually owned strips of arable crops within the fields adjacent to the villages. The commonly owned multifunctional areas of land away from the village were used for activities such as communal grazing and the collecting of wood. They were often on poorer soils and were less intensively managed. In Estonia, some parts of the former commons were also used as temporary slash and burn fields (Ligi, 1963).

Fire has played an important role in traditional agriculture and landscape management in many regions of Europe. The use of fire in Britain on moorlands to promote game is still a widespread practice, as emphasized in a review by Grant, Mallord, Stephen, and Thompson (2012). The burning of heathlands has also been common practice in European countries such as Germany, The Netherlands (Goldhanmmer and Bruce, 2004), Norway (Hjelle, Halvorsen, & Overlandet, 2010) and Sweden (Hamilton, 1997).

Slash and burn is currently usually associated with tropical environments or, in Europe, with the Neolithic period. However, it is not widely known that the use of fire was also widespread throughout the Baltic region and also in the Black Forest in Southern Germany (Goldhanmmer and Bruce, 2004). The literature does show (Ligi, 1963; Kahk, 1992; Meikar & Uri, 2000) that fire cultivation was present in Estonia, but not how the practice has affected landscapes and habitats, hence the study described in the present paper.

Today prescribed fire is mainly used in nature conservation and landscape management, except in Britain where it is used for game management on moorlands. In southern Europe, the methods of prescribed burning are discussed by Fernandes et al. (2013). In Finland and Sweden prescribed burning is recommended for forest restoration and as a method for nature conservation (Hekkala, Tarvainen, & Tolvanen, 2014; Lovén & Äänismaa, 2004; Niklasson and Drakenberg, 2001 etc.). Examples of the best practice of prescribed fire use are given by Montiel and Kraus (2010). In Estonia prescribed burning is not used as conservation tool.

The present paper poses the following hypotheses:

- Fire cultivation played an important role in the formation of the patterns in traditional cultural landscapes in Southern Estonia.
- Changes in the agricultural practices in the Nineteenth Century created a new structure of farmland connected with the decline of slash and burn cultivation.
- The former *buschlands* used in slash and burn are identifiable in present landscapes.
- Knowledge of the historical significance of slash and burn is essential for the development of policies for nature conservation in Southern Estonian landscapes.

1.1. Overview of the occurrence of fire cultivation and its impact on landscapes in the Baltic region

Throughout the Baltic countries slash and burn cultivation was a widespread practice. In the hilly, forested areas in Småland in Southern Sweden, slash and burn cultivation was common, even until the end of the Nineteenth Century. In central Sweden, the practice was connected with the Forest Finns, the Finnish migrants who colonized the Scandinavian Boreal region. Slash and burn in mature forests was prohibited by law in 1647 in all state land, due to lack of timber, and was therefore restricted to vegetation of young trees and scrub until the beginning of Twentieth Century (Hamilton, 1997).

In Finland fire cultivation and its impact on forests was studied at the beginning of the Twentieth Century (Heikinheimo, 1915). In the eastern regions of Finland–in Karelia and Savo–slash and burn cultivation was still practised until the 1930's (Voionmaa, 1987). By the beginning of the Twentieth Century in some parishes in Eastern Finland up to 75% of the land had been used for slash and burn fields (Heikinheimo, 1915). The importance of large scale forestry increased in Finland, at the same time as in Sweden, and in 1929 burning was therefore restricted in the former country (Goldhanmmer & Bruce, 2004).

In Russia, fire cultivation was a common practice in the St Petersburg, Novgorod and Pskov regions, as well as in Russian Karelia (Heikinheimo, 1915). In the central part of European Russia, slash and burn was used up to the 1940's and, in the north, even until the 1960's (Bobrovskii, 2010).

In the Baltic region, therefore, slash and burn agriculture had an important role in rural landscapes over several hundred years. In Finland historical slash and burn cultivation has been taken into consideration in the process of designating Natura 2000 habitats (Eriksson, 2008). There is one Annex One Habitat in the Habitats Directive related to slash and burn—9070: Fennoscandian Wooded Pastures. This habitat consists of woodlands with deciduous trees where the land was opened for grazing after slash and burn cultivation, and occurs in the eastern part of Finland (Eriksson, 2008).

1.2. Overview of the status of fire cultivation in Estonia

In Estonia the duration and extension of slash and burn management has been underestimated by landscape and natural scientists for many years. Slash and burn cultivation has been studied primarily from an historical perspective. The Estonian historian Ligi (1963) is the main author cited in connection with the practice.

Slash and burn management is one of the oldest agricultural practices in Estonia. Evidence of the use of slash and burn cultivation has been dated to the Bronze Age (Lang, 2007). This cultivation practice lasted until the end of the Nineteenth Century. According to ethnographical data, there were cases of slash and burn used for clearing new fields even at the beginning of the Twentieth Century, as described by Jääts, Kihno, Tomson and Konsa (2010). In Northern and Western Estonia the importance of slash and burn cultivation was already declining in the Middle Ages and fire was used more to prepare new fields or to get temporary extra crops. In Southern Estonia slash and burn cultivation remained significant as an independent cultivation practice for much longer. For example, in the Eighteenth Century as much as half of the annual crop was produced from slash and burn (Ligi, 1963). The data concerning Nineteenth Century agricultural history in Southern Estonia are relevant also to the northern part of contemporary Latvia because both these regions originally belonged to the former province of Livonia.

Ligi (1963) has described two different traditional agricultural management strategies in Estonia. One was typical of the west and north and the other of the south and east. This pattern results from the differences in bedrock. In Southern Estonia, the soils are acidic because they are derived from the Devonian Sandstone bedrock which is covered by variable depths of moraine deposits. The soils derived from this material are therefore acidic and low in nutrients. On such soils the ash from the burnt wood helps to modify the inherent acidity and increase fertility. Slash and burn was therefore an effective cultivation method in that period. In contrast, in Northern and Western Estonia, the bedrock is Silurian or Ordovician Limestone and soil acidity is not therefore a limiting factor for agriculture.

The term ‘fire cultivation’ includes several different agricultural practices. For slash and burn cultivation, an area was cleared of trees which were then burned to provide ash which subsequently served as fertiliser. After three to five years of cultivation, the plot was abandoned, because of the decline in nutrient levels, and the vegetation was left to regenerate. Two types of slash and burn cultivation have been described by historians. The first was the burning of mature forests and the second involved setting fire to land covered by relatively young trees and shrubs, which had colonised land which had previously been cultivated using the slash and burn practice (Meikar & Uri, 2000).

On Nineteenth Century maps a special land category was used for these regularly burned patches of land (Fig. 1). These were labelled as *buschland* in the local Baltic-German dialect. This land was used for growing temporary crops and was separated from the permanent fields in which crops were grown regularly and fertilized with manure: therefore *buschland* was often covered by young trees that had colonized the bare ground after cultivation.

There is no equivalent scientific term for *buschlands*. The word scrub is used in the scientific literature for similar vegetation structures, as described by Barkmann (1990), but his definition is for ecological formations mainly of multi-stemmed bushes. This definition is therefore not suitable for describing *buschlands* because on the fallow of slash and burn fields the regenerated young trees mainly consist of single stems. Therefore, the term *buschland* is used throughout the present paper to cover land of this type.

Some patches of about 0.5–1.0 ha were chosen every year for fire cultivation from the *buschland* patches. The dominant tree species in these areas according to historical sources were silver birch (*Betula pendula*), grey alder (*Alnus incana*) and Norway spruce (*Picea abies*) (Ligi, 1963). These species also produce plentiful seed, as well being good colonizers of bare ground. Regular cycles of slash and burn management were carried out according to agrarian law (Lihwlandi-ma tallorahva Sesdus, 1820) as a minimum 21 year cycle.

Buschlands were also used for grazing in the first years following abandonment of crops as a type of long term fallow. After the trees had begun to colonize wood was collected for firewood (Fig. 2).

There has been some confusion as how to interpret the areas marked as *buschland* in the maps of the Nineteenth Century. Some non-historian authors have interpreted these as areas with an unclear land cover (Raet et al., 2008). As the practice of fire cultivation, and hence this special land category, does not exist in modern agriculture, it has sometimes been difficult to accept that there is no other explanation for these particular areas.

2. Materials and methods

The study areas are in the Karula National Park, in Southern Estonia, as shown in Fig. 3.

Karula National Park is designated as a Natura 2000 site (Estonian Government, 2004). The nature conservation objectives of Karula National Park are to protect rare species and habitats

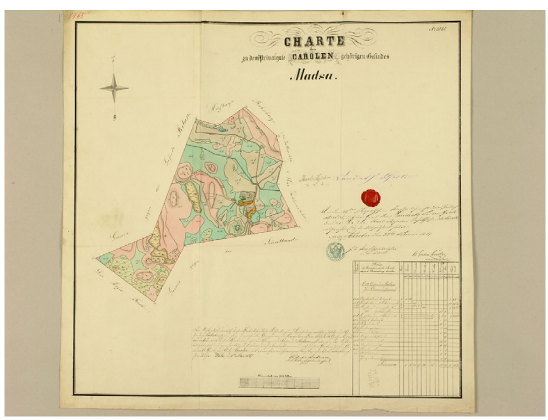

Fig. 1. Nineteenth Century farmland map (EAA 2469). The pink areas (labelled as c) are *buschland*. Yellow with red dots indicate the farmyards, dark grey—vegetable garden, grey—permanent arable fields, olive green—pastures, green—hay meadows, mixed brown and green—wetlands, beige—coniferous forest, dark green—deciduous forest. The grey dispersed lines on the pink patches indicate slopes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Time interval	Status	Function
1-2 year	clear cutting, drying wood and burning	tree clearance
3-5 years	managed crops	growing crop
4-6 years	fallow, few tree seedlings	grazing
6-10 years	colonisation by young trees	light grazing
10-21 years	complete tree cover	extraction of wood for firewood/ fences

Fig. 2. Management cycle of a *buschland* plot.

listed in EU directives, maintain the landforms and landscapes which are typical to Southern Estonia, to protect nature values, maintain the cultural heritage and provide the balanced usage of environment (Estonian and Government, 2006). Estonian National parks are not exactly in accordance with the IUCN definition of category II National Park: “Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities” (Dudley, 2008). The conservation aims of Karula National Park also contain the elements of IUCN category V “Protected landscapes” and VI “Protected areas with sustainable use of natural resources”.

Karula National Park (12,300 ha) is an area with a complex relief and variable landscapes, located in the southern uplands which reach a maximum altitude of 137 m. Up to 86% of the Park is covered by natural landscapes such as forests, wetlands and lakes whilst managed land such as fields, semi-natural grasslands, farm buildings and roads cover the remaining 14%. The National Park is inhabited by 270 people. The land is owned mostly by the state (73%) and private land owners (27%) (Environment Board, 2007), but before World War II, the proportion of private farms was slightly higher. This paper considers only the former privately owned farmland because only the maps of these areas were available.

The present study is based on analysis of cadastral maps of 51 farms dating from the 1860–1870’s, which were geo-referenced and digitized. These maps were drawn up for land purchase and are now maintained in National Archives (EAA 2469). These maps (scale 1:4200) cover an area of 3574.9 ha, but actually, 3557.7 ha inside the National Park were analysed in the present study because some farms had land outside the Park. Only maps which could be geo-referenced accurately were used. Even then, some patches or borders might have been moved a little, because of the insufficient accuracy of the Nineteenth Century maps. On these maps, permanent fields, *buschlands*, hay meadows, pastures and other less important land-use units of the Nineteenth Century are delineated. Some pastures contained trees in the Nineteenth Century. Many farms had a few separately located hay meadows at some distance from the main farm unit, often by the banks of rivers or lakes. These meadows are not included in the analysis because there are no recognisable landmarks available on the maps to provide exact locations. Therefore, only the meadows used for hay in the main parcels of farmland were analysed. Probably the maps reflect a slightly earlier situation than the date shown. It is also possible that some of the *buschlands* were in use as permanent fields at the time the map was drawn. Nevertheless, by using these maps it is possible for general analysis to identify the plots regularly used for

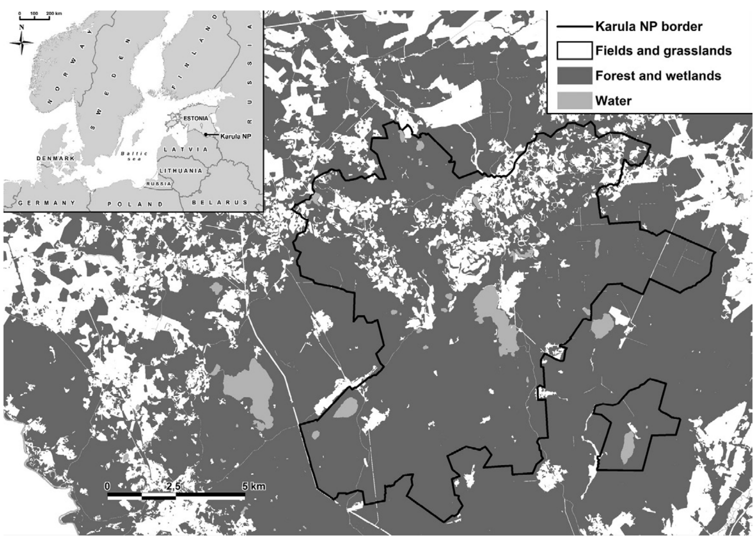

Fig. 3. Location of the study area.

fire cultivation with reasonable precision. To analyse the land cover changes classes were adopted: arable fields (which includes also the small areas of gardens, farmyards and roads), grasslands (hay meadows and pastures), forest (coniferous and deciduous forests and wetlands) and water.

The distribution of *buschlands* was also checked by analysing Nineteenth Century land cover in the Haanja uplands in Southern Estonia by digitising the map of Saaluse manor (EAA 2072.4.164 sheet 1). The map from 1886 was used, which divided the land into plots before it was sold, with 27 farms being included covering 1036.4 ha. This map is similar in its features to the Karula farmland maps and it was manipulated in the same way.

Land cover changes in Karula were analysed by comparison of the digitised topographical maps from the successive dates. The Russian map was termed One-Verst and was completed in 1894–1915 at the scale 1:42000. This map was used to examine the situation at the beginning of the Twentieth Century. Land cover in the middle of the Twentieth Century, at the start of the period of Soviet collectivization was obtained from the topographical map at the scale 1:50,000 completed in 1950's. Cadastral Map from 1985–1987 (1:10,000) was used to characterise the Soviet period. All these maps are electronically available (Land Board, 2014). The Estonian Digital Basic Map (1:10,000) was used to provide recent coverage. To unify the information, four categories of land cover were distinguished based on local landscape features and the tasks of study: the category "field" (arable fields, bare areas, buildings and roads are aggregated), "grasslands" (wet and dry semi-natural grasslands), forests and wetlands (forest, scrub, felled areas, bogs and fens) and "waters". This classification resulted from what land cover types were differentiated on the used maps and reflects the maximum number of common units.

Digitization of the One-Verst and topographical map from the 1950's may have caused some errors because of their smaller scale, but more detailed maps from this period were not available. In addition, in the process of digitization it was sometimes difficult to decide the borders of the patches, because only symbols without definite contours are used on the maps in some places. These errors might be misleading if the interest is in the history of a certain land patch or small area. These maps were therefore used to characterize the general trends in land cover, which is the aim of the present study.

The MapInfo Professional 10.0 programme was used for manipulating and comparing the maps. For each map, the areas of land cover classes were calculated. To follow the changes in land cover classes, each class of the earlier map was overlaid with the later map and changes were analysed. In order to reduce random errors, areas smaller than 0.1 ha were eliminated at every step during the comparison of time periods. The results were analysed in Microsoft Excel 2010.

The Forest Management database and the database of Natura Habitats were also used to characterize the forest stands that had regenerated on former agricultural land.

During preliminary fieldwork, 20 former *buschland* sites were visited in Karula and photographed to obtain an impression of their current appearance.

2.1. Importance of fire cultivation in traditional landscapes in Southern Estonia

The results of the map analyses indicate that *buschlands* occupied an important position in the Karula upland landscape in the Nineteenth Century and accounted for the largest proportion (35%) of the total area of the farms in the study area, followed by land covered by grassland (28%) and permanent fields (25%). The remainder of the land surface was covered by fens, bogs, small woodlands and water bodies, as shown in Table 1. As the separated hay meadows were not included in the analysis, their proportion is underestimated in the landscape: but this does not significantly alter the results because of their small area.

In the Saaluse farmlands in Haanja upland the *buschlands* were even more common, covering 45% of the farmland, while permanent fields covered 20%, pastures and hay meadows 24% and residual land such as wetlands 8%. The large proportion of *buschlands* was not therefore only characteristic in Karula and the study can be considered to reflect the overall situation in Southern Estonia in the Nineteenth Century.

The slash and burn parcels were located mostly on the slopes and tops of hills, as shown in Fig. 4, because ploughing and transportation of dung for annual cultivation was difficult and involved much labour. The permanent arable fields were located on flatter land.

Table 1
Land cover changes from the Nineteenth Century to 1900, 1950, 1980 and 2000 (approximately). Areas of land cover categories are in hectares.

Land cover in Nineteenth Century	Land cover	~1900	>1950	~1980	>2000
Arable fields 875.0	Arable fields	791.8	780.8	458.0	377.5
	Grasslands	56.4	56.0	17.3	205.6
	Forest	10.5	13.6	159.2	209.8
	Water	0.0	0.0	0.8	0.8
Buschlands 1261.7	Arable fields	866.4	753.0	198.4	140.4
	Grasslands	112.2	86.5	120.7	134.7
	Forest	265.8	402.5	899.2	960.1
	Water	0.0	0.0	0.7	0.8
Hay meadows and pastures 984.6 (grasslands)	Arable fields	363.1	331.4	92.8	54.8
	Grasslands	392.2	367.6	156.1	87.1
	Forest	199.2	253.5	668.4	786.9
	Water	1.5	1.1	6.0	11.5
Forest 388.4	Arable fields	81.9	63.3	10.1	2.2
	Grasslands	54.4	40.2	14.1	12.4
	Forest	241.1	271.7	348.6	311.9
	Water	0.3	0.3	0.3	4.9
Water 48.0	Arable fields	5.3	3.8	0.2	0.0
	Grasslands	7.3	10.4	0.8	0.2
	Forest	4.9	2.2	16.7	15.9
	Water	35.0	31.4	33.7	35.1

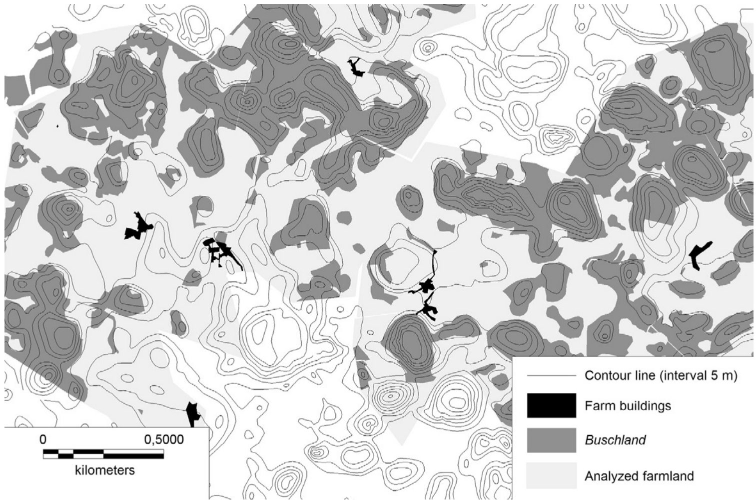

Fig. 4. A close view of a fragment of the study area. The comparison of the map of farms with relief, showing that the *buschlands* location was mostly on the hills.

The maps show that, by the beginning of the Twentieth Century, crucial changes had occurred in the land cover and landscape appearance. The *buschlands* had declined, with 72% being converted into arable land, 19% into forest and 9% into meadows. During the Twentieth Century, the *buschland*s underwent further major changes. By the present time, 78% of *buschland*s had become forest, whereas 72% of the former permanent fields have remained as open land, as shown in Fig. 5.

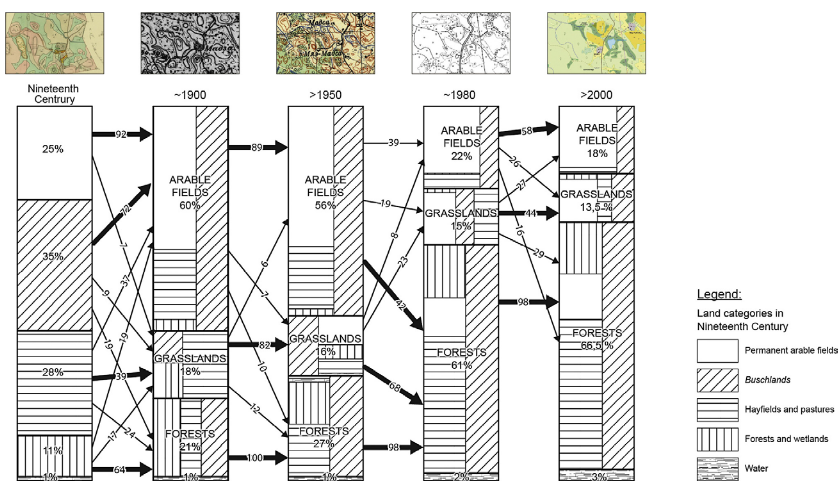

Fig. 5. Changes of land cover in the farmed land of Karula. The columns in the chart show the distribution of land cover over time whereas the arrows show the transition of the land covers into the next period. The different shading patterns inside the columns shows the proportion of Nineteenth Century land cover categories in different periods. Transitions of less than 5% are not shown.

Arable land declined steadily through the time sequence, matched by increases in grasslands and forest, as shown in Table 1. Almost the same area of grasslands became arable as remained unchanged. Some grasslands became forest at first. However, subsequently the forest cover also increased elsewhere. The forest and wetlands increased at the expense of former agricultural land, while water remained nearly stable.

The forest cover showed a major increase between the 1950's and 1980's in Karula, as elsewhere in Estonia (Palang et al., 1998). The new forests mainly replaced the former *buschlands* and wet meadows.

These results show that 35% of the farmland was covered by *buschlands*. It is likely that the whole management cycle of slash and burn was about 21 years, with an individual plot being cultivated for three years on average, as enacted by the imperial law (Lihwlandima tallorahva Seädus, 1820). The regeneration of patches of trees took a minimum of six years, therefore it was possible for the young trees to grow up for a minimum of 15 years before the next burning and cultivation cycle. These calculations show, that in pre-industrial landscapes in Karula 63% of the slash and burn areas and 20% of the whole farmed area was covered by young trees forming scrub, although the location of the tree cover patches changed in time. The term young trees is used because, as stated above, they consisted of birch, spruce and alder which are not shrubs. A similar pattern can also be considered to be typical of other hilly areas in Southern Estonia. Consequently, these areas of scrub were an important feature of pre-industrial farmland and the appearance of the landscapes was more variable and significantly different from the period before the Second World War or the contemporary situation.

Throughout the Twentieth Century, the former *buschlands* underwent new major changes, with 79% becoming forest. The main proportion of the secondary forests in the region are therefore derived from former *buschlands*. The majority of forests in the former *buschlands* are associated with hilly land in Karula because the terrain was unsuitable for mechanized agriculture. The slopes were initially colonized by young trees, forming scrub which eventually became forest. The permanent arable fields are on the more flat and fertile areas. The former slash and burn patches have therefore changed the most in the landscape, whereas the arable fields have remained stable.

Within the forests now growing on the former *buschland* plots identified during preliminary fieldwork, traces of the original agriculture remain with features such as relict field margins and pits in the bottom of slopes, which were excavated to store turnips over the winter. There are also individual large relict trees, which originated from the end of fire cultivation when the former *buschlands* were used for grazing. More detailed studies of the traces of slash and burn cultivation in the forests are needed in future.

The changes in land use did not only affect the *buschlands*, since the pastures and hay meadows also began to change at the end of the Nineteenth Century. Thus, the parts of the unproductive meadows that were very wet were abandoned, probably because the farmers started to cultivate clover on the fields to improve the quality of the hay (Kahk, 1992). In addition, approximately 30% of the land analysed on the maps as pastures and hay meadows were converted into arable land, as shown in Fig. 5. Only 39% were mapped as grasslands at the beginning of the Twentieth Century, whereas by that time the original wet pastures, mostly woodland pastures, had been mapped as forests. These numbers do not cover all the changes of grasslands because the separately located hay meadows are excluded, as mentioned before.

2.2. Discussion of the role of fire cultivation in development of cultural landscapes and their associated values

The appearance of the *buschlands* changed during the cycle of fire cultivation. At first, they had the appearance of arable fields, but then became fallow land with regenerating trees, leading to scrub and eventually young forests, depending on the stage of the management cycle. The *buschlands* were therefore unique in their usage and appearance and there is therefore no comparable category of land in contemporary landscapes.

At the end of the Nineteenth Century the patches of scrub that originally formed the *buschlands* finally disappeared from rural landscapes. As slash and burn agriculture only occupied such an important position in Southern Estonia, the distinct period characterized by the ending of slash and burn management is restricted to this region of the country. In Northern and Western Estonia, fire cultivation had declined much earlier and this break point cannot therefore be so easily defined.

Fire cultivation declined during the same period as other major social changes were taking place in Estonian land holdings. The common lands were parcelled out and landlords sold the farms as property to the former peasants. The new landowners were committed to use their land more intensively and therefore at first transformed the majority of the *buschlands* into arable fields. The industrialisation and modernisation of society changed the attitudes of rural people. The availability of up to date knowledge improved due to newspapers and magazines. New agricultural techniques were adopted and the ancient three field system was abandoned and replaced by crop rotations to maintain fertility. New crops, such as potatoes and clover, were introduced by farmers. This process was more pronounced in Southern Estonia than elsewhere in the country (Viires, 1998).

The main regions covered in most Estonian landscape history studies have been the west and north. The majority of studies are focused on the landscape changes in the Twentieth Century because of the readily accessible maps available for such texts, for example the original One-Verst Map from 1894–1913 which covers almost all Estonia. Many Nineteenth Century estate and farm maps are preserved in the archives but have only been relatively easy to find in public databases in recent years. These maps do not cover large areas and it is often complicated to geo-reference them. The landscape history of Southern Estonia, including the importance of slash and burn agriculture and the changes at the end of the Nineteenth Century, have therefore been neglected in the landscape literature before the present study. Southern Estonia fits well into the periods described by Antrop (2005). Well defined break points can be distinguished between the periods and the traditional landscapes belonging to the period before the Twentieth Century are clear, as described in the present paper. By contrast, in Northern and Western Estonia traditional and modern landscapes merge imperceptibly.

Identification of former *buschlands* within present landscapes is straightforward once their origin is understood. During the Twentieth Century, most of them have developed into forest patches located on the hills and with surrounding fields and hay meadows currently still in agricultural use (Fig. 6). This landscape pattern is considered to be specific to the Karula National Park and reflects land use history and needs "translation" from the original pre-modern structure. Land use history provides the key to understanding the contemporary landscape. The current study has demonstrated conclusively that the described landscape pattern is not very old or traditional but does have a distinctive cultural value because, once it is understood, the contemporary landscape pattern expresses land use history. The aesthetic value of this landscape is connected with the observed variability and is a result of

Fig. 6. The forests on the small hills designate the former *buschlands* in Karula. The specific landscape pattern is of forested hills surrounded by open fields. The question discussed in the text is: can this be called a traditional cultural landscape? Photo by Arne Ader.

interactions between geology and land use history. The appearance of the landscape is picturesque and has been highly valued in the context of nature conservation objectives (Environment Board, 2007).

In the Karula National Park 29% of *buschlands*, which were mapped as forests at the beginning of the Twentieth Century, are designated as Natura 2000 habitats in the Natura Habitats database, mostly as the Western Taiga type. Also, 52% of the former *buschlands*, where the forests are 100 years or older, are designated as Natura 2000 habitats in this database. The first number is smaller because some of the forests, developed before the One-Verst Map was drawn up, had already been felled during the Twentieth Century. The land use history was not known at the time of designation of the Natura habitats and the possible impacts of former fire cultivation on some landscape patches was not taken into account.

In the text of the Interpretation Manual of European Union Habitats (European Commission, 2013) Western Taiga is considered to qualify within the Annex One list if it is natural old forest as well as young forests naturally developed after fire.

The oldest forests derived from the former slash and burn patches are 170 years old in Karula and are the product of natural regeneration. Many of the stands have remained undisturbed for several decades and have the comparable appearance of Old Growth forests, as shown in Fig. 7. These forests have a relatively natural structure with many rotten logs and dead trees and therefore are likely to have a rich flora of fungi living on the dead wood, as well as saproxylic insects. These trees have died firstly from self-thinning and secondly from being senescent old individual, large, relict trees. As the *buschlands* were used for grazing after cultivation, the old trees have wide crowns, because they were formed in open landscapes Recently the literature has references to forests with natural structure being considered as old growth (Hilbert & Wiensczyk, 2007; Mosseler, Thompson, & Pendrel, 2003), although in the past the definition was much stricter. However, whether these forests contain Ancient Woodland Indicators (Hermy, Honnay, Firbank, Grashof-Bokdam, & Lawesson, 1999) and, therefore, how they can be interpreted in terms of Natura 2000 requires further work to define the resources of biodiversity.

Fire has been a significant presence in these landscapes for many centuries. Forest fires have also played an important role in boreal forest ecology, changing the succession and composition of the tree cover. How the slash and burn cultivation has affected the soil conditions, and therefore the biological condition of forest biotopes, is not yet clear. Many Finnish researchers consider the forests in

Fig. 7. A former *buschland* overgrown at the beginning of the Twentieth Century which now has the appearance of a natural forest.

the former slash and burn land to be semi-natural biotopes (Uotila & Kouki, 2005; Vanha-Majamaa et al., 2007). There is some evidence, that former slash and burn patches are characterized as having higher vegetation diversity than natural forests (Hokkanen, 2006). Myllyntaus and Mattila (2002) have emphasized that there is no agreement in Finland if slash and burn cultivation has caused any permanent impact on the characteristics of forests. There are data suggesting that fire affects the soil (Delgado-Matas, 2004; Viro, 1974) but how long these impacts last in boreal forests is not so clear. The modelling dynamics of soil organic matter show, that the impact of slash and burn management on the soil may persist even up to 120 years in the Boreal region (Bobrovsky, Komarov, Mikhailov, & Khanina, 2010). As the impacts of former fire cultivation on the boreal forest are not well understood, it is not possible to give specific guidelines for their management.

The role of secondary forests in protected areas needs further attention, because many European protected sites are located in remote areas where traditional extensive farming is declining significantly. The maintained remnants of traditional forms of land use have to coexist with new dynamic wild areas. Both parts of the landscape need appropriate, well defined management goals and techniques suited to local conditions (Höchtl, Lehringer, & Konold, 2005). In most cases there is not sufficient information to predict the future value of the new biotopes and therefore to plan appropriate management. Historical information can be used to estimate the potential value of such new forests, and to set up targets for restoration or development of biodiversity linked to such sites once such resources have been assessed. Old slash and burn forests could form a "model" to predict the potential natural value of the younger secondary forests in the former slash and burn cultivation sites, which were transformed into arable fields at the beginning of Twentieth Century.

As shown by Antrop (2005) and Marucci (2000), landscape history is a valuable tool to help make valid planning decisions. An understanding of landscape history is essential in the design of appropriate policies for maintenance of valuable landscapes, otherwise important elements will not be protected. As elsewhere in Europe, traditional rural landscapes are valued in Estonia for their high cultural values and specific biodiversity. Land use history provides the basic information to determine conservation objectives, as initially described by Hoskins (1970). If nature conservation planners take the model from the Northern and Western Estonia where the slash and burn management declined earlier than in Southern Estonia, then the targets for nature conservation management will not be appropriate. Karula and other protected areas in the South Estonia therefore need well defined objectives related to their individual history.

Over time, some new landscapes and habitats are formed and some disappear, mainly as a result of human activities. However, the determination of which habitats and landscape elements are most valuable remains problematic, as does the period when a given landscape was in an "ideal" state. Although to the general observer the Karula farmed landscape appears natural, the present paper shows that it is necessary to explain its evolution, so that the public can appreciate the history of its development. It is also necessary to emphasise that change is an integral part of the development of valued landscapes.

Traditional landscapes in Southern Estonia have been formed gradually in pre-modern times and have changed not only in the Twentieth Century but also previously in the Nineteenth Century. It might not therefore be realistic to plan to restore any particular historical pattern but rather to accept the maintenance of the contemporary landscape with its modern aesthetic and cultural values.

3. Conclusions

The historical analysis has demonstrated that slash and burn was an important agricultural management practice from the Bronze Age until the mid-Nineteenth Century. This cultivation method then began to decline and had ceased by the beginning of the Twentieth Century. Slash and burn cultivation is surprisingly little studied in Europe but evidence of its impact on the current landscape pattern exists even today.

The Nineteenth Century maps allowed the examination of the parcels of traditional farm landscapes and the location of the former slash and burn cultivation areas. In farmlands in Karula National Park, most of the former slash and burn areas were transformed into arable fields by the beginning of Twentieth Century. In the second half of the Twentieth Century these fields gradually turned into forest because they were too steep for mechanized tillage. About 20% of slash and burn parcels had already regenerated into forest by the end of Nineteenth Century and are now covered by mature stands of trees.

The paper has therefore shown for the first time that in rural Estonia, slash and burn has played an important role in the formation of landscapes. The former fire cultivation sites are now mainly forest and occur in specific locations on the tops and slopes of hills.

This study has therefore shown that the forests on the former slash and burn sites have an important status in Karula National Park, because of their large area and high proportion of old grown forest. The forests formed on the previous slash and burn land need further study to investigate their differences in terms of biodiversity from other forests.

Estonian National Archives

1. EAA 2072.4.164 sheet 1. General-Charte von dem privaten Gute Salishof. 1886
2. EAA 2469. Liivimaa Maakrediidi Selts.

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References

Antrop, M. (2005). Why landscapes of the past are important for the future. *Landscape and Urban Planning*, *70*(1–2), 21–34. http://dx.doi.org/10.1016/j.landurbplan.2003.10.002

Barkmann, J. J. (1990). A tentative typology of European scrub and forest communities based on vegetation texture and structure. *Vegetatio*, *86*, 131–141. http://dx.doi.org/10.1007/BF00031729

Bobrovskii, M. V. (2010). Effect of the historical land use on the structure of forest soils in European Russia. *European Soil Science*, *43*(13), 1458–1466. http://dx.doi.org/10.1134/S1064229310130053

Bobrovsky, M., Komarov, A., Mikhailov, A., & Khanina, L. (2010). Modelling dynamics of soil organic matter under different historical land-use management techniques in European Russia. *Ecological Modelling*, *221*(6), 953–959. http://dx.doi.org/10.1016/j.ecolmodel.2009.12.013

Delgado-Matas, C. (2004). Dynamics of nutrients in slash and burn agroforestry in Koli National Park. In L. Lovén (Ed.), *Tutkittu ja tuntematon Koli* (915) (pp. 29–46). Metsäntutkimuslaitoksen Tiedonantoja.

Dudley, N. (Ed.). *Guidelines for Applying Protected Area Management Categories. IUCN, Gland*. (2008). ⟨http://cmsdata.iucn.org/downloads/guidelines_for_applying_protected_area_management_categories.pdf⟩.

Environmental Board. Karula rahvuspargi kaitsekorralduskava 2008–2018 (Management plan of Karula National Park 2008–2018). (2007). ⟨http://www.keskkonnaamet.ee/public/Karula_rahvuspargi_kodulehe_materjalid/Karula_RP_KKK_2008-2018.pdf⟩.

Estonian Government. (2004). *Euroopa Komisjonile esitatav Natura 2000 võrgustiku alade nimekiri* (111) RTL (The list of Natura 2000 sites proposed to EU Commission).

Estonian Government. (2006). *Karula rahvuspargi kaitse-eeskiri* (31) RTI (Protection rules of Karula National Park).

Eriksson, M. O. G. Management of Natura 2000 habitats. 9070 Fennoscandian wooded pastures. European Commission. (2008).⟨http://ec.europa.eu/environment/nature/natura2000/management/habitats/pdf/9070_Fennoscandian_wooded_pastures.pdf⟩.

European Commission. (2013). *Interpretation manual of European union habitats. EUR.*

Fernandes, P. M., Davies, G. M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., et al. (2013). Prescribed burning in southern Europe: Developing fire management in a dynamic landscape. *Frontiers in Ecology and the Environment*, *11*, e4–e14. http://dx.doi.org/10.1890/120298

Goldhammer, J. F., & Bruce, M. (2004). The use of prescribed fire in the land management of Western and Baltic Europe: An overview. *International Forest Fire News*, *30*, 2–13. ⟨http//www.fire.uni-freiburg.de/iffn/iffn_30/01-IFFN-30-Europe.pdf⟩.

Grant, M. C., Mallord, J., Stephen, L., & Thompson, P. S. (2012). *The costs and benefits of grouse moor management to biodiversity and aspects of the wider environment: A review.* Bedfordshire: RSPB.

Hamilton, H. (1997). Slash and burn in the history of Swedish forests. *Rural Development Forestry Network Paper*, *21f*, 19–24. ⟨http//www.odi.org.uk/publications/754-slashburn-history-swedish-forests⟩.

Heikinheimo, O. (1915). *Kaskiviljelyksen vaikutus Suomen metsin (The impacts of slash and burn cultivation in the Finnish Forests).* Helsinki: Metsähallituksen julkaisuja II.

Hekkala, A., Tarvainen, O., & Tolvanen, A. (2014). Dynamics of understory vegetation after restoration of natural characteristics in the boreal forests in Finland. *Forest Ecology and Management*, *330*, 55–66. ⟨http://dx.doi.org/10.1016/j.foreco.2014.07.001⟩.

Hermy, M., Honnay, O., Firbank, L., Grashof-Bokdam, C., & Lawesson, J. E. (1999). An ecological comparison between ancient and other forest plant species of Europe, and the implications for forest conservation. *Biological Conservation*, *91*(1), 9–22. http://dx.doi.org/10.1016/S0006-3207(99)00045-2

Hilbert, J., & Wiensczyk, A. (2007). Old-growth definitions and management: A literature review. *BC Journal of Ecosystems and Management*, *8*(1), 15–31. ⟨http://www.forrex.org/publications/jem/ISS39/vol8_no1_art2.pdf⟩.

Hjelle, K. L., Halvorsen, L. S., & Overland, A. (2010). Heathland development and relationship between humans and environment along the coast of western Norway through time. *Quaternary International*, *220*, 133–146. http://dx.doi.org/10.1016/j.quaint.2009.09.023

Höchtl, F., Lehringer, S., & Konold, W. (2005). Wilderness: What it means when it becomes a reality––a case study from the South-Western Alps. *Landscape and Urban Planning*, *70*, 85–95. http://dx.doi.org/10.1016/j.landurbplan.2003.10.006
Hokkanen, P. (2006). Environmental patterns and gradients in the vascular plants and bryophytes of eastern Fennoscandian herb-rich forests. *Forest Ecology and Management*, *229*, 73–87. http://dx.doi.org/10.1016/j.foreco.2006.03.025
Hoskins, W. G. (1970). The making of the English landscape (1). London.
Jääts, L., Kihno, K., Tomson, P., & Konsa, M. (2010). Tracing fire cultivation in Estonia. *Forestry Studies*, *53*, 53–65. http://dx.doi.org/10.2478/v10132-011-0089-3
Kahk, J. (1992). Uuenduste sissetung 18 sajandi lõpust 19 sajandi keskpaigani (Innovations invasion in the late 18th century to mid-19th century). In J. Kahk (Ed.), *Eesti talurahva ajalugu* (pp. 365–377). Tallinn.
Koppa, H. Ajaloolised kaardid maakasutuse dünaamika uurimisallikana Vana-Kuuste mõisa näitel (Land cover changes as indicated by historical maps: The case study from Vana-Kuuste manor, Estonia). (2006). ⟨http://dspace.utlib.ee/dspace/bitstream/handle/10062/1174/koppahelle.pdf?sequence=5⟩.
Koppel, K. Maakasutuse uurimise metoodika Kasaritsa uurimisala (Rõuge kihelkond) 17–19 sajandi külamaastike kujunemise näitel (The research methods of historical land use as exemplified by the formation of rural landscapes on Kasaritsa study area (Rõuge parish) in 17th–19th centuries). (2005). ⟨http://dspace.utlib.ee/dspace/handle/10062/1263⟩.
Land Board. Ajaloolise kaardid (Historical maps). (2014). ⟨http://geoportaal.maaamet.ee/est/Teenused/Kaardirakendused/Ajaloolised-kaardid-p157.html⟩.
Lang, V. (2007). The bronze age and early iron ages in Estonia. *Estonian Archaeology*, *3*, 298 (Tartu).
Ligi, H. (1963). *Põllumajanduslik maakasutus Eestis XVI–XVII sajandil. (Agricultural land use in Estonia in XVI–XVII century)*. Tallinn.
Lihwlandi-ma tallorahva Seädus. (1820). *Essimenne-Kolmas jaggu. (Agrarian law of the livonian governorate. first–third section)*. Tartu.
Lovén, L., & Äänismaa, P. (2004). Planning of the sustainable slash-and-burn cultivation programme in Koli national park, Finland. *International Forest Fire News*, *30*, 16–21. ⟨http -//www.fire.uni-freiburg.de/programmes/natcon/Finland%20Koli%20GFMC%20Edit.pdf⟩.
Maandi, P. (2010). Land reforms and territorial integration in post-Tsarist Estonia, 1918–1940. *Journal of Historical Geography*, *36*(4), 441–452. http://dx.doi.org/10.1016/j.jhg.2010.03.005
Marucci, D. J. (2000). Landscape history as a planning tool. *Landscape and Urban Planning*, *49*, 67–81. http://dx.doi.org/10.1016/S0169-2046(00)00054-2
Meikar, T., & Uri, V. (2000). Võsamaade majandamisest Eestis. Eesti metsad ja metsandus aastatuhande vahetusel (Of the management of bushland in Estonia). In T. Meikar, & I. Etverk (Eds.), *Akadeemilise metsaseltsi toimetised XI* (pp. 103–120). Tartu.
Montiel, C., & Kraus, D. (Eds.). (2010). Best practices of fire use-prescribed burning and suppression fire programmes in selected case study regions in Europe. *Forest Institute Research Report, 24*. ⟨http://www.efi.int/files/attachments/publications/efi_rr24.pdf⟩.
Mosseler, A., Thompson, I., & Pendrel, B. A. (2003). Overview of old-growth forests in Canada from a science perspective. *Environmental Reviews*, *11*, 1–7. http://dx.doi.org/10.1139/a03-018
Myllyntaus, T., & Mattila, T. (2002). Decline or increase? The standing timber stock in Finland, 1800–1997. *Ecological Economics*, *41*(2), 271–288. http://dx.doi.org/10.1016/S0921-8009(02)00034-4
Niklasson, M., & Drakenberg, B. (2001). A 600-year tree-ring fire history from Norra Kvills National Park, southern Sweden: Implications for conservation strategies in the hemiboreal zone. *Biological Conservation*, *101*, 63–71. http://dx.doi.org/10.1016/S0006-3207(01)00050
Raet, J., Sepp, K., & Kaasik, A. (2008). Assessment of changes in forest coverage based in historical maps. *Forestry Studies*, *48*, 67–78. http://dx.doi.org/10.2478/v10132-011-0056-z
Palang, H., Mander, Ü., & Luud, A. (1998). Landscape diversity changes in Estonia. *Landscape and Urban Planning*, *41*(3–4), 163–169. http://dx.doi.org/10.1016/S0169-2046(98)00055-3
Palang, H., Spek, T., & Stenseke, M. (2011). Digging in the past: New conceptual models in landscape history and their relevance in peri-urban landscapes. *Landscape and Urban Planning*, *100*(4), 344–346. http://dx.doi.org/10.1016/j.landurbplan.2011.01.012
Pedroli, B., van Doorn, G., de Blust, G., Paracchini, M. L., Wascher, D., & Bunce, F. (Eds.). (2007). *Europe's living landscapes. Essays exploring our identity in the countryside*. KNNV Publishing (The Netherlands).
Uotila, A., & Kouki, J. (2005). Understorey vegetation in spruce-dominated forests in eastern Finland and Russian Karelia: Successional patterns after anthropogenic and natural disturbances. *Forest Ecology and Management*, *215*(1–3), 113–137. http://dx.doi.org/10.1016/j.foreco.2005.05.008
Vanha-Majamaa, I., Lilja, S., Ryömä, R., Kotiaho, J. S., Laaka-Lindberg, S., Lindberg, H., et al. (2007). Rehabilitating boreal forest structure and species composition in Finland through logging, dead wood creation and fire: The EVO experiment. *Forest Ecology and Management*, *250*(1–2), 77–88. http://dx.doi.org/10.1016/j.foreco.2007.03.012
Veski, S., Koppel, K., & Poska, A. (2005). Integrated palaeoecological and historical data in the service of fine-resolution land use and ecological change assessment during the last 1000 years in Rouge, southern Estonia. *Journal of Biogeography*, *32*, 1473–1488. http://dx.doi.org/10.1111/j. 1365-2699.2005.01290.x
Viires, A. (1998). Tagasivaade (Retrospect). In A. Viires & E. Vunder (Eds.), *Eesti rahvakultuur* (pp. 655–666).Tallinn.
Voionmaa, V. (1987). History of the Karelian tribe in Finland-extracts. *Suomen Antropology*, *4*, 207–212.
Viro, P. J. (1974). Effects of forest fire on soil. In T. T. Kozlowski, & C. E. Ahlgren (Eds.), *Fire and ecosystems* (pp. 7–45).New York.

II

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Chapter 16
Historical Development of Forest Patterns in Former Slash and Burn Sites in Southern Estonia

Pille Tomson, Robert Gerald Henry Bunce and Kalev Sepp

Abstract Slash and burn is one of the oldest methods of clearing and fertilizing land for growing crops. The practice continued in Estonia until the beginning of the twentieth century. The historical background to the use of fire in Estonia is first described, including the legal controls that were set up. After cultivation the slash and burn fields left as fallow, before trees were allowed to regenerate for up to 20 years, when the cycle started again. The term *buschland* from the local Baltic German dialect was used on documents to designate the land that had been used for regular burning—a land use category that no longer exists. The literature on the environmental impact of slash and burn is discussed but there is no agreement about the effects of the practice on soil. The effects on biodiversity have also not been widely studied. The study area was the Karula National Park in Southern Estonia. Maps from the end of nineteenth century were compared with contemporary digital map and databases using Mapinfo. In the nineteenth century the *buschlands* occupied 34 % of farmland but the analyses showed that now 77 % had become forest, with the remainder being grasslands or arable. These changes were because the sites were on hills and the slopes were too steep for modern agriculture. The dominant tree species, forest types and soils are also described and are associated with infertile conditions.

Keywords Slash and burn · Land use history · Forest biodiversity · Biocultural diversity

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16.1 Introduction

Slash and burn is one of the oldest methods of agriculture for clearing and fertilizing land to grow crops. The practice consists of a cycle of burning trees, growing crops for some years, leaving the land fallow and then allowing regeneration of trees before starting again. During the Neolithic period in Europe slash and burn was widely used, as described by Pyne et al. (1996). In the modern world the practice is usually associated with the tropics.

In Northern Europe slash and burn cultivation lasted until the twentieth century. In Finland the use of slash and burn is well known, as Heikinheimo (1915) compiled a comprehensive overview of this method when it was still being used. In the eastern part of Finland—in Savo and Karjala—fire cultivation continued until the 1930s, as described by Voionmaa (1987). In Southern Sweden slash and burn was also used in Smalånd. The forest Finns were responsible for the introduction of the practice to central and western areas of Sweden, such as Värmland and Dalecarlia (Hamilton 1997; Wedin 2003). Forest Finns also introduced fire cultivation into Norway (Wedin 2003). In the forests of North-Western Russia slash and burn was used even until the 1960s (Bobrovskii 2010).

Often the impacts of fire and fire cultivation on ecosystems are examined together, as described by Pyne et al. (1996) and Goldhammer and Furyaev (1996). In a different context, Grant et al. (2012) also emphasized, in a review of the effects of rotational burning of moorlands, that, even today, the full environmental impacts of the use of fire are still not understood. Some relevant literature is not widely available because it is written in languages such as Swedish, Finnish and Russian.

In Estonia it is widely understood that slash and burn cultivation belonged to prehistoric times. It has been suggested that in slash and burn regions, dry oligotrophic pine forests underwent soil erosion following burning (Laasimer 1958). Some species-poor spruce forests are also thought to be the result of prehistoric slash and burn cultivation (Rõuk 1995; Paal 1997).

At the same time, the Estonian historians have described the wide use of fire in agriculture between the seventeenth and nineteenth centuries (Ligi 1963; Kahk 1992; Tarkiainen 2014). Slash and burn cultivation was a characteristic feature of pre-modern agriculture before the changes that took place at the end of the nineteenth century. The recent literature shows that, according to the records of ethnographical inventories, slash and burn cultivation persisted until the end of nineteenth century and in some cases even in the twentieth century (Jääts et al. 2010). Anecdotal evidence comes from an 86-year-old lady who recalled hearing in childhood from her grandfather about slash and burn at the end of the nineteenth century, as recorded in summer 2014 by the senior author in Rõuge parish, Southern Estonia.

The aim of present study is to provide the first description of current forests on former slash and burn sites, using existing databases and maps from the nineteenth century and then to analyse the factors underlying the formation of these forests.

16.2 Fire Cultivation in Estonia

Ligi (1963) described slash and burn as part of the agricultural land use system typical of the Southern Estonia. In the eighteenth century approximately half of the annual crop yield was harvested from slash and burn fields (Ligi 1963). In Northern and Western Estonia the limestone bedrock meant that the ash from burnt wood did not have the same fertilizing effect as in Southern Estonia, where the soils are acid because they are on moraines derived mainly from the Devonian sandstone bedrock, although other materials are also present. Forest regeneration on abandoned slash and burn fields on shallow limestone soils is also relatively slow in comparison with Southern Estonia (Ligi 1963).

The contrasting history of slash and burn management in the regions of Estonia is also reflected in legislation. Southern Estonia belonged in the nineteenth century to the Livonian Covernatore, whereas Northern Estonia was in the Estonian Covernatore. In the Livonian Peasant Law from 1819 (Lihwlandi-ma tallorahva… 1820) mainly targeted to the liberation of the peasants, there are strict rules for slash and burn management. The rules are that the break between the burnings must be 24 years and that no more than three crops can be taken from the same field during this cycle. In contrast the concurrent Estonian Peasant Law (Eestima Tallorahwa… 1816) provides only the rules for liberation and the peasant's self-government.

In the nineteenth century slash and burn was only used in young forests. The regular burning of the old forests was stopped in Estonia already in the seventeenth century due to the lack of timber (Etverk 1974).

In young forests the regular burning cycle took place every 30 years in the seventeenth century but the interval between burnings was decreased until 15–20 years in the nineteenth century (Meikar and Uri 2000). After burning the land was ploughed, harrowed and seeded or the seeds were put into soil with a type of harrow. Rye, barley and turnip were the most common crops in slash and burn fields. Fields were cultivated for 2-5 years after burning and after that were left as fallow and used for grazing. Tree regeneration then commenced and after 10–15 years the *buschland* was ready for the next burning event (Meikar and Uri 2000).

The special land category, termed *buschland* in the local Baltic German dialect, was used on maps and documents to designate the land that had been used for regular slash and burn cultivation. (Meikar and Uri 2000). The local south Estonian dialect did not separate the forests used for timber and the *buschlands*, as both were named "*mõts*". The term "*mõts*" was also used even if there was no tree cover on the *buschland* at that particular time. Even today old people in the southern Estonia use the term "*mõts*" if they are talking about herding cattle to pasture. This name may be connected with the point that at an earlier date slash and burn cultivation was also used in mature forests. However, the use of the term also shows that slash and burn cultivation was an integral part of many wooded areas. This peculiarity of terminology might be caused some misunderstandings of ethnographical records, because in the official Estonian the word "*mets*" is used only in the meaning of forests.

There have been different views as to the fate of *buschlands* after the decline of slash and burn management. They have been regarded as grasslands (Liitoja-Tarkiainen 2006) or as pastures or forests with wood production becoming increasingly important (Ratt 1985; Meikar and Uri 2000). *Buschlands* were also considered to be the main land resource to increase arable land (Ligi 1963; Koppel 2005; Tarkainen 2014).

16.3 Biodiversity Connected with Slash and Burn Cultivation

There are different opinions about the tree species composition of *buschlands*. Many authors state that birch was the dominant species (Ligi 1963; Öpik 1992; Viires 2000). However, mixed forests with birch and spruce are also mentioned (Öpik 1992; Meikar and Uri 2000). In Finland grey alder is also common in former slash and burn sites (Heikinheimo 1915). Probably, in the *buschlands* birch or grey alder were the main species and in the old forests slash and burn cultivation were carried on in mixed stands.

Heikinheimo (1915) described the impacts of fire cultivation on the forests in Finland according to different zones around the settlements. The nearest and most regularly used areas were dominated by grey alder. In the second less used areas birch was the major species and in the outermost zone pine dominated. Spruce was dominant only outside the third zone which had not been used for slash and burn. Also, aspen was present in slash and burn areas.

Pine seeds are more resistant to fire than those of spruce. In addition, pine trees were often available for seed dispersal as they were common in uncultivated sites such as rocky outcrops, bogs and sandy places inside the slash and burn zones (Heikinheimo 1915). The special method "huuhta" was used in mature coniferous forests in the eastern part of Finland (Tarkiainen 2014).

Many authors have pointed out that slash and burn has caused soil degradation and thus has led to changes in vegetation (Laasimer 1958; Rõuk 1995; Paal 1997). Laasimer (1958) in particular considers that the dry oligotrophic pine forests in South-Eastern Estonia are a result of soil erosion after slash and burn cultivation. Rõuk (1995) and Paal (1997) consider that species-poor spruce forests are the result of slash and burn cultivation and Paal (1997) also includes species-poor spruce, aspen and birch forests.

Historical data about soil quality in slash and burn sites are not consistent. There are opinions that the soils in *buschlands* were poorer (Ligi 1963) or more fertile (Koppel 2005) than in permanent arable fields.

The impacts of fire on soils mainly depends on the intensity of the heat, which is related to the amount of organic material, which in slash and burn will be correlated with the length of time since the last burning but also the weather conditions (Delgado-Matas 2004). All authors agree that the pH of soils rises immediately after burning but the organic matter decreases, the amount of cations increase and mineral nitrogen suitable for plant growth also increases after burning (Viro 1974; Reintam and Moora 1983; Pyne et al. 1996; Delgado-Matas 2004), but there are few data indicating the persistence of these changes. According to Viro (1974) some changes may persist until 50 years.

The same authors describe erosion after slash and burn management, but this is the result of opening the soil surface and is not specific to the use of burning. Some authors argue that slash and burn cultivation promotes podsolization (Reintam and Moora 1983). Ligi (1963) on the other hand states that regular slash and burn cultivation slowed down the rate of podsolization.

16.3.1 Materials and Methods

On the base of historical data, it is clear that slash and burn was a significant factor in Southern Estonian rural landscapes. In order to investigate impacts of this factor, a case study was carried out in the Karula National Park (Fig. 16.1). The Park (12,300 ha) is an area with a complex relief and variable mosaic landscapes located in the uplands of South-Eastern Estonia. The conservation aims of the Park are to preserve the natural biotopes and also to maintain semi-natural habitats as well as

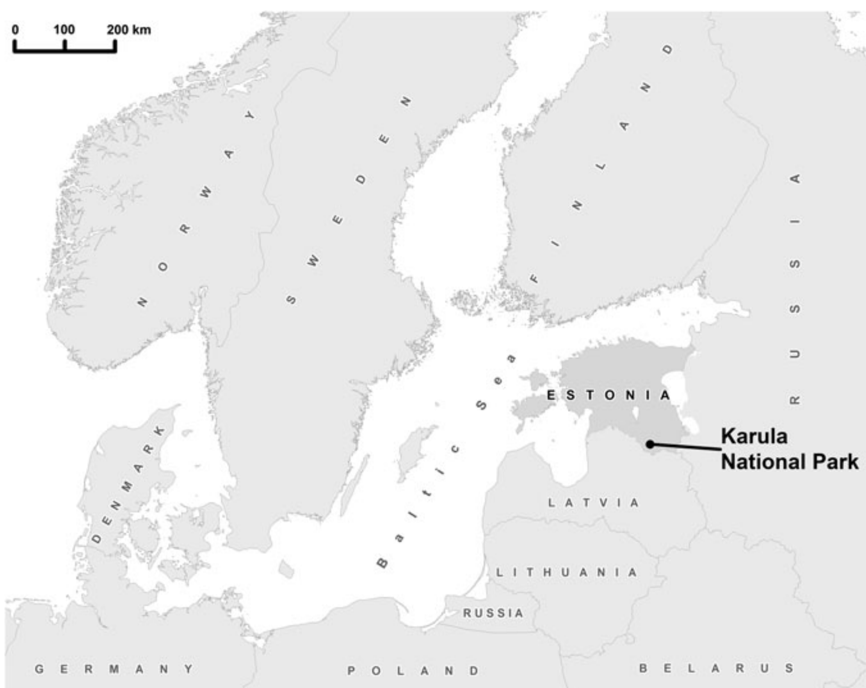

Fig. 16.1 Location of study area

traditional rural landscapes and their associated cultural heritage. Karula National Park does not correspond exactly to Category II of the International Union for the Conservation of Nature (IUCN), which national parks consisting of natural or near-natural habitats (Dudley 2008). Agricultural land covers 12 % of the Park, whereas forests and wetlands cover 83 %, water bodies 3 % and other categories 2 % (Karula rahvuspargi kaitsekorralduskava 2007).

In order to characterize pre-modern land use and locate the former *buschlands* 51 maps (Estonian National Archives, record EAA 2469) from 1870 to 1880 were geo-referenced and digitized (Fig. 16.2). The maps (scale 1:4200) cover a 3755 ha in study area. These maps were drawn up for land purchase at the end of the nineteenth century and the distribution of different land cover types is shown. The maps cover account for 62 % of the historical farmlands located on the territory of present-time Karula National Park so the results of study are representative of the

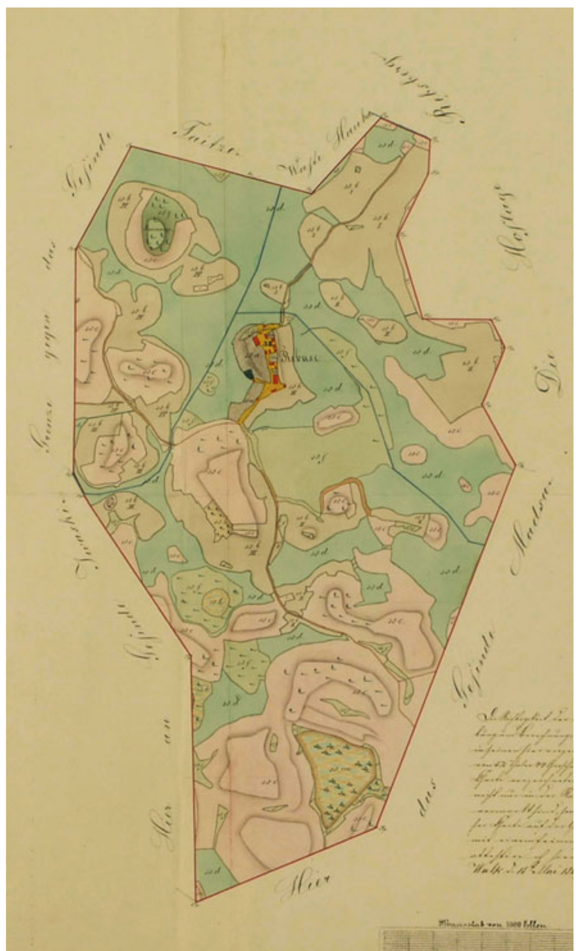

Fig. 16.2 The nineteenth century map of Rebase farm. *Pink areas* indicate the *buschlands*, *yellow with red dots*—farmyard, *dark grey*—vegetable garden, *grey*—permanent arable fields, *olive green*—pastures, *green*—hay meadows, *mixed brown and green*—wetlands, *beige*—coniferous forest, *dark green*—deciduous forest. The *grey dispersed lines* on the *pink patches* indicate slopes

whole rural landscape of Karula. On these maps, there are marked permanent arable fields, *buschlands*, hay meadows, pastures and other land use patches present in the nineteenth century, making it possible to examine their historical allocation.

To identify the character of the former slash and burn lands today comparisons were made with contemporary maps and databases. The current Estonian Basic Map, which is digitally available, was used to identify the contemporary situation.

The Estonian Digital soil map was used to identify the soil conditions. This database consists the data about soil types according to Estonian soil classification (Vabariigi digitaalse… 2001). In this paper the names of soils are presented according to the World Reference Base (WRB), adapted by Astover et al. (2012).

The digital forest management dataset was used to establish the main forest characteristics. This dataset consists of information on each forest stand. The age, dominant species and types of forest were used from this database. In the forest management dataset the forest type site classification of Lõhmus (2004) was used. In the present paper the similar forest classification of Paal (1997) is used to describe the forest site types and provide names. For the forest site type classes the names are used according to Paal (2007), because Lõhmus (2004) gives no names in English. The "age" and "dominant tree species" refer to the upper tree layer.

MapInfo Professional 10.0 programme was used for comparing the maps. Digitized maps were used to calculate the areas of land use types. In the Park borders the *buschland* and other land use patches layers were overlaid with the other databases and results were analysed in Microsoft Excel 2010. Although two farms were partly outside the Park, the forest and soil analyses were only made inside the boundary.

The Latin names of the species quoted in the text are as follows: birch (*Betula pendula*), spruce (*Picea abies*), pine (*Pinus sylvestris*), grey alder (*Alnus incana*) and aspen (*Populus tremula*).

16.3.2 The Characteristics of Former Slash and Burn Sites

The analyses of nineteenth century maps show that *buschlands* form the main part of farmlands at that time, and cover 1267 ha (34 %). The arable fields covered 825 ha (22 %), hay meadows 655 ha (17 %), pastures 382 ha (10 %), woodlands 195 ha (5 %), wetlands 276 ha (7 %), water bodies 48 ha (<2 %), vegetable gardens 25 ha (<1 %), roads and yards 23 ha (<1 %) and areas unidentifiable on the maps cover 57 ha (<2 %).

The comparison of the nineteenth century map with Estonian Basic Map shows that at the present time the landscapes have changed and the former slash and burn lands are now mainly covered by forests: 952 ha (77 %) are forest, 135 ha (11 %) are mapped as grasslands, 124 ha (10 %) as arable fields, 16 ha (1 %) as other open areas and 8.6 ha (<1 %) as all other classes (water, wetlands and scrub). Secondary forest is therefore the main land cover containing biodiversity in the former slash and burn parcels.

As elsewhere in Estonia as well as in Karula National Park much former agricultural land has been covered by regenerated forest during the second half of the twentieth century. Among these secondary forests (1567 ha in study area) forests on former *buschlands* cover the largest area 911 ha (58 %). Forests have colonized grasslands cover 472 ha (30 %) and those growing on former permanent arable fields 184 ha (12 %).

The soil types on *buschlands* are mainly Albeluvisols 660 ha (53 %), which are soils typical of the southern margin of the boreal forest that have been affected by peri-glacial activity and are somewhat acidic. In study area the most common soil unit of Albeluvisols is Haplic. Regosols in study area are the eroded soils with shallow humus layer and they cover the 346 ha (28 %). Less widespread are Luvisols, brown soils of the cool temperate zone, 94 ha (8 %) and Podzols 26 ha (2 %). Other soil types cover 108 ha (9 %). In the secondary forests on the former *buschlands* the proportions of soils are a little different: Albeluvisols cover 572 ha (61 %), Regosols 189 ha (20 %), Luvisols 56 ha and (6 %), Podzols 26 (2 %) and other soil types cover 108 ha (9 %).

The main species in the forests formed on the *buschlands* are pine 353 ha (41 %), birch 267 ha (31 %), grey alder 116 ha (13 %), spruce 114 ha (13 %) and aspen 17 ha (2 %).

The forests of former slash and burn sites according to the forest database are mostly the *Oxalis* site type mesotrophic boreal forests, 447 ha. The *Hepatica* site type (172 ha) forests are more fertile in their character and occur the site type class eutrophic boreo-nemoral forests according to Paal (1997). The more fertile *Aegopodium* site type occurs less widely (55 ha). The more dry and poor soil site types are represented by the *Oxalis-Vaccinium vitis idea* (80 ha) and *Oxalis-Vaccinium myrtillus* (16 ha) site types. All the other less presented site types cover 60 ha. The *Oxalis* forests are typical to the former *buschlands*, 69 % of this type forests on farmlands grow on *buschlands*, 8 % of *Oxalis* type forests on farmlands grow on the former arable fields, 7 % on the former pastures, 6 % on the former hay meadows and 10 % were forests and wetlands in nineteenth century.

The age of these secondary forests is approximately between 10 and 170 years, with the most common age group being between the ages of 60 and 70 years, as shown in Fig. 16.3. During the period after the Second World War, forest also developed on much agricultural especially on hay meadows. In the former *buschlands* the regeneration of forests started much earlier and continued until the early twentieth century.

16.3.3 Discussion: Factors Shaping the Biodiversity of Former Slash and Burn Sites

In Karula farmlands the *buschlands* were the most common land use at the end of nineteenth century, with other types being less common. On the old maps they were clearly linked with hills as visible in Fig. 16.2. The slopes and tops of these small

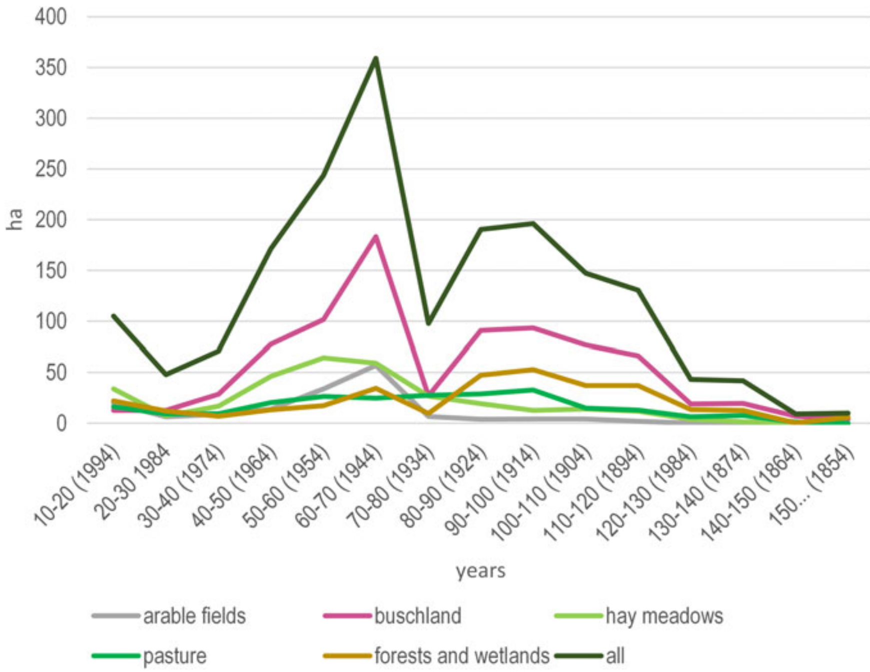

Fig. 16.3 The area of age classes of agricultural patches in the study area

hills were not easy to cultivate as permanent arable fields because of difficulties in transporting the dung up to the slopes for fertilization, as well as problems of ploughing the steeper slopes. Slash and burn cultivation evolved as an effective way of growing crops in those areas and, as shown below, they were also linked with acidic soils. Relief was therefore probably the one of the factors which determined the extent and persistence of fire cultivation on hills in Karula throughout the nineteenth century. Tarkiainen (2014) argues that according to the agricultural books from the seventeenth century the slopes were most suitable for slash and burn, because of the dry soils. Open slopes were probably preferred, because the cut wood needed to dry before burning.

Even although there are no ethnographical records from the Karula parish about slash and burn, the large area of *buschlands* suggests that the fire cultivation was as important here as elsewhere in Southern Estonia.

The former *buschlands* lost their previous function by the end of nineteenth century and were mainly converted into fields, grasslands or forests (Meikar and Uri 2000; Koppel 2005; Liitoja-Tarkiainen 2006; Tarkiainen 2014, Tomson et al. 2015). However, by the end of twentieth century most of the former *buschlands* had become forests.

The main reason for the land abandonment during the second half of the twentieth century has been mechanization. In the former Soviet countries the impacts of collectivization need to be considered (Nikodemus et al. 2005).

In Estonia during 1961–1989, 21.2 % of nationalized and collectivized agricultural land was transferred into state forest land (Kasepalu 1991).

The same trends can be also observed in Karula (Fig. 16.3). The abandonment of the wet grasslands and cultivated areas on the steep slopes is evident. Some differences are present notably the rapid increase of forest regeneration in the period following the end of the Second Wold War and the slow increase in secondary forest on the former of slash and burn sites during the nineteenth and early twentieth centuries.

The period from the second part of the nineteenth century is identified as a time of change in agriculture by Estonian historians (Kahk 1992). There was introduction of crop rotation, clover cultivation and an increase in cattle breeding. The oldest forests on the former slash and burn patches, therefore, date from the nineteenth century. Among these forests are patches, which are the first generation after the end of slash and burn cultivation. The formations of forest on the *buschland*s at the end of nineteenth century and at the beginning of the twentieth century reflect the changed understanding of farmers because the woodlands were progressively valued as a resource to supply the timber for modernizing farm complexes and living houses. The development of these new forests was a slow process, which lasted for decades. Other types of agricultural land were not remarkably abandoned during that period.

The need for timber increased because of the new buildings needed for modern cattle breeding and the wood was more valued, so some farmers decided to encourage forest regeneration at the beginning of the twentieth century. Before the twentieth century forest management was important in the forests belonging to Manor houses but not to those linked to farmland (Meikar 2014). The plantation of coniferous became more common on farmlands in 1930s (Etverk 1974). Also, some forest patches on farms showed re-growth following clear cuts at the beginning of the twentieth century, especially in the category "forests and wetlands" of Fig. 16.3. Increases in land drainage also encouraged forest regeneration on wetlands.

The major part of the former cultivated land, on the previous *buschland*, turned into forest before the Second World War. However, the peak of forest regeneration came between 1944 and 1954 which is not possible to explain with mechanization because the tractors were introduced into Karula in the middle of 1950s so must have been due to social factors discussed below. Some forests also started to colonize former permanent arable fields and wet meadows.

In 1941 and 1949, the Soviet authorities deported a large number of people from Karula parish (Merila-Lattik 2005) which could have led to the decrease in cultivation in subsequent years. The years during and just after the Second World War were hard for rural people and fields became abandoned causing the observed increase in forest cover. Tree regeneration started not only in abandoned fields, but also in forest land after clear cutting, but it is unlikely that the latter was widespread during the war, when the economy was under pressure and the reduced manpower available was needed to ensure survival.

The subsequent land abandonment, caused mainly by mechanization, lasted to the 1970s. This process is similar for that which took part throughout Estonia

(Kasepalu 1991). Probably, the regeneration of clear cuttings is more important in this period.

Among the secondary forests in Karula National Park the forests in the former slash and burn cultivation sites cover the biggest proportion first, because *buschlands* were most common in farmlands and second, more of the former *buschlands* were abandoned than permanent arable fields. The second major groups are the wet forests on the former grasslands. These forests are highly visible elements in the landscape because of their location on the hills.

These forests can be characterized by two age groups: the forests that started to grow before the Second World War and those that started to grow after, because the factors that led to their formation were different. The different age groups on the former *buschlands* are characterized also by different dominant tree species (Fig. 16.4). Birch and alder grow in the younger patches which started to generate after the Second World War, when Estonia became a part of Soviet Union. The large area of fast-growing deciduous trees such as birch and grey alder is specific to abandoned arable land. Spruce and pine were also planted and afforestation on agricultural land was also common in the Soviet period (Kasepalu 1991). The older *buschland* forests are dominated by pine. Fire cultivation can also encourage pine (Heikinhemo 1915).

Albeluvisols were appropriate for fire cultivation because of their relatively high acidity which could be improved by the wood ash and also because of the location of these kinds of soils in the moraine hills (Astover et al. 2012). There are some differences in the soils of these two age groups of forests in former *buschland*

Fig. 16.4 The dominant tree species of the forests in former *buschland*

(Fig. 16.5). The eroded soils (Regosols) are more common in the younger groups and the infertile Podzols are more widely present in the older forests.

The major portion of eroded soils in the areas of younger forests reflect the longer period in cultivation and probably also the impact of mechanized cultivation. Probably, the patches in better soils were cultivated longer and were more affected by erosion. Also, the fertilization and tillage during the management of the fields has probably influenced later forest growth, but how much is not clear.

The smaller proportion of eroded soils among the soils of older forest patches reflects the lack of mechanized tillage and shorter cultivation period with a longer time for soil recovery. The occurrence of Podzols among the old *buschland* forest soils shows that in the period of modernization of agriculture at the end of nineteenth century, the areas with the poorest soils were abandoned first thus repeating a pattern that is well known elsewhere in Europe.

In low-intensity agriculture, the soil properties do not change very much, specially the subsoils (Köster and Kõlli 2013). Some impacts of fire may persist for 50 years or more (Viro 1974), but this do not change the soil type. The podzolization must be depressed on the *buschlands* in comparison with other forests on the same soils. The herb cover in the pasture stage of fallow and the subsequent cover of deciduous trees do not promote leaching.

The results do not confirm that slash and burn cultivation in the Nordic region has caused permanent soil degradation because of erosion, as argued before by Laasimer (1958).

Soil types are connected with forest site type (Lõhmus 2004). The typical forest site on Albeluvisols according to Paal (1997) is the *Oxalis*-*Vaccinium myrtillus* site type, which is less common on former *buschlands* in Karula. The most common site type among the *buschland* forests is the *Oxalis* site type, which is also the most

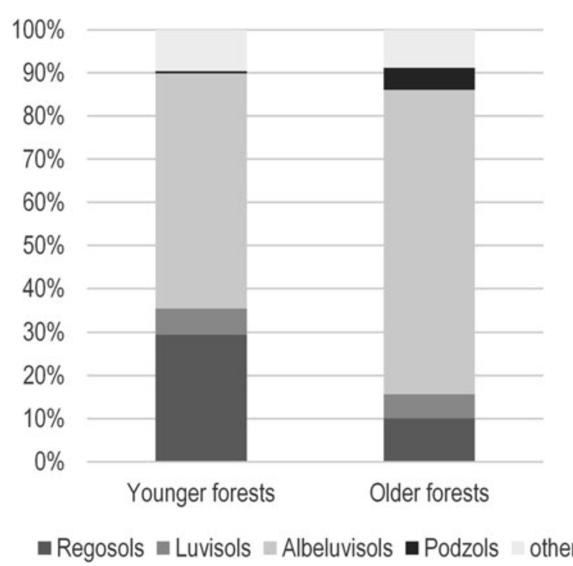

Fig. 16.5 The soils of afforested *buschlands*

common type in the Southern Estonia (Paal 1997). The *Oxalis* site type is common in forests on former farmlands but less widespread on state forest land, which originally in the nineteenth century belonged to the owners of manor houses. More fertile areas suitable for cultivation were colonized by forests in historical times and Albeluvisols, which today is considered largely as not suitable for agriculture (Astover et al. 2012) were often used for slash and burn cultivation (Ligi 1963).

Oxalis site type of forest is also common in the former *buschlands* with eroded soils. The eutrophic boreo-nemoral forests cover relatively larger area amongst the eroded soils compared with those in other forest types. The more fertile soils were more impacted by agriculture.

The results do not confirm, or reject, the hypothesis that the dry oligotrophic pine forests were formed by cultivation practices in the former slash and burn areas, as argued by (Laasimer 1958). These results do, however, fit the opinion, where species-poor spruce forests are connected with slash and burn cultivation in many areas (Paal 1997; Rõuk 1995), because usually the dominant tree species in the *Oxalis* site type is spruce (Paal 1997). This is probably because of the selection of this particular soil type for slash and burn agriculture due to its relatively low fertility and location.

The long-term impact of slash and burn on soil quality has not been finally determined. It is difficult to see that any further progress can be made without intensive studies of soil characteristics in slash and burn sites in comparison with control areas on the same soil type. The same applies to impacts of the practice on biodiversity although a study is in progress to assess differences in vegetation between slash and burn sites and other forests.

16.4 Conclusions

Fire cultivation is a land use management practice, whose impact has been insufficiently studied in Estonia. In Southern Estonia such cultivation was still used even in the nineteenth century. Comparisons between old and modern maps enabled the characteristics of the former slash and burn sites to be determined. Slash and burn covered about 34 % of farmland in Karula at the end of the nineteenth century. The changes in agricultural practices, which started at the end of that century, created new forest patterns connected with the intensification of farming and the associated decline in fire cultivation. In the second half of the twentieth century, the forest cover in the former slash and burn sites increased again due to their location on slopes and tops of hills, not suitable for mechanized cultivation. Former slash and burn parcels have therefore had the most changeable land use in Karula. The forests on sites formerly used for slash and burn cultivation are therefore of relatively recent origin in farmland landscapes.

Forests in former slash and burn patches are mostly of the mesotrophic boreal forest, *Oxalis* site type. This forest site type is not so common on forests on other former agricultural land. The younger forests on formerly slash and burn lands also have impacts following the cessation of agriculture. Whether the forest type is the result of fire cultivation, or if fire cultivation was practiced on land suitable for the Oxalis forest site type, is not clear.

The history of slash and burn cultivation offers a good example of how inherent natural conditions have led to the formation of the current pattern of land use. Land use history needs to be understood in order to interpret the contemporary biodiversity patterns. The extent and strength of the impacts of fire cultivation on biodiversity, particularly vegetation, needs future study.

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References

Astover A, Kõlli R, Roostalu H, Reintam E, Leedu E (2012) Mullateadus. Õpik kõrgkoolidele (Soil science. Textbook for Highschools). Eesti Maaülikool, Tartu

Bobrovskii MV (2010) Effect of the historical land use on the structure of forest soils in European Russia. Eur J Soil Sci 43(13):1458–1466. doi:10.1134/S1064229310130053

Delgado-Matas C (2004) Dynamics of nutrients in slash and burn agroforestry in Koli National Park. Dynamics of nutrients in slash and burn agroforestry in Koli National Park. In: Lovén L (ed) Tutkittu ja tuntematon Koli. Metsäntutkimuslaitoksen tiedonantoja, vol 915, pp 29–46

Dudley N (ed) (2008) Guidelines for applying protected area management categories. IUCN, Gland. http://cmsdata.iucn.org/downloads/guidelines_for_applying_protected_area_management_categories.pdf. Accessed 26 Oct 2014

Eestima Tallorahwa Seädmissed (1816) Estonian Peasant Law. http://digar.nlib.ee/digar/show/?id=100923. Accessed 26 Oct 2014

Etverk I (1974) Metsa õpitakse tundma ja kasutama (Forest had been learned to know and use). In: Valk U, Eilart J (eds) Eesti metsad (Estonian forests). Valgus, Tallinn

Goldammer JG, Furyaev VV (eds) (1996) Fire in ecosystems of boreal Eurasia. Kluwer Academic Publisher, Dordrecht

Grant MC, Mallord J, Stephen L, Thompson PS (2012) The costs and benefits 565 of grouse moor management to biodiversity and aspects of the wider 566 environment: a review. RSPB, Bedfordshire

Hamilton H (1997) Slash and burn in the history of Swedish forests. Rural Development Forestry Network Paper, 21f, pp 19–24. http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/1162.pdf. Accessed 26 Oct 2014

Heikinheimo O (1915) Kaskiviljelyksen vaikutus Suomen metsin (The impacts of slash and burn cultivation in the Finnish Forests). Metsähallituksen julkaisuja II, Keisarillisen senatiin kirjapainossa, Helsinki

Jääts L, Kihno K, Tomson P, Konsa M (2010) Tracing fire cultivation in Estonia. For Stud 53:53–65. doi:10.2478/v10132-011-0089-3

Kahk J (1992) Uuenduste sissetung 18. sajandi lõpust 19. sajandi keskpaigani (Innovations invasion in the late 18th century to mid-19th century). In: Kahk J (ed) Eesti talurahva ajalugu (History of Estonian peasants). Olion, Tallinn

Karula rahvuspargi kaitsekorralduskava 2008–2018 (The management plan of Karula National Park 2008–2018) (2007). http://www.keskkonnaamet.ee/public/Karula_rahvuspargi_kodulehe_materjalid/Karula_RP_KKK_2008-2018.pdf. Accessed 10 Oct 2014

Kasepalu A (1991) Mis peremees jätab, selle mets võtab (That which the master leaves, the woods will take). Valgus, Tallinn

Koppel K (2005) Maakasutuse uurimise metoodika Kasaritsa uurimisala (Rõuge kihelkond) 17.-19. sajandi külamaastike kujunemise näitel (The research methods of historical land use as exemplified by the formation of rural landscapes on Kasaritsa study area (Rõuge parish) in 17th–19th centuries). Retrieved from http://dspace.utlib.ee/dspace/handle/10062/1263

Köster T, Kõlli R (2013) Interrelationships between soil cover and plant cover depending on land use. Est J Earth Sci 62(2):93–112. doi:10.3176/earth.2013.08

Laasimer L (1958) Nõmmealade geobotaaniline iseloomustus ja areng Eestis. Nõmmealade taasmetsastamise ja nõmmemetsade majandamise küsimusi (The geobotanical characterization and development of oligotrophic sites in Estonian. The reforestation oligotrophic sites and management of oligotrophic forests). ZBI, Tartu, pp 29–43

Ligi H (1963) Põllumajanduslik maakasutus Eestis XVI–XVII sajandil (Agricultural land use in Estonia in XVI–XVII century). Tallinn

Lihwlandi-ma tallorahva Seädus (1820) Essimenne-Kolmas jaggu (Agrarian Law of the Livonian Governorate. First-Third Section). Tartu

Liitoja-Tarkiainen Ü (2006) Talukõlvikud Vooremaal 17.-19. sajandil (Farmland's land use patches in Vooremaa in 17th–19th century). In: Tamberg T (ed) Vene aeg Eestis. Uurimusi 16. sajandi keskpaigast kuni 20.sajandi alguseni (Russian time in Estonia. Studies from the mid-16th century until the early 20th century). Eesti Ajalooarhiivi Toimetised, vol 14(21). Tartu, pp 229–254

Lõhmus E (2004) Eesti metsa kasvukohatüübid (Estonian forest site types), 2nd edn. Eesti Loodusfoto, Tartu

Meikar T (2014) Riik ja talumetsad Eesti Vabariigi eel (State and forests of farms before Estonian Republic). Eesti Mets 2:44–50

Meikar T, Uri V (2000) Võsamaade majandamisest Eestis. Eesti metsad ja metsandus aastatuhande vahetusel (Of the management of bushland in Estonia). In: Meikar T, Etverk I (eds) Akadeemilise Metsaseltsi Toimetised, vol XI. Tartu, pp 103–120

Merila-Lattik H (2005) Karm ja kaunis Karula. Elust, olust ja inimestest muinasajast tänapäevani (Rough and beautiful Karula. The peoples and way of life from ancient times to the present day). Eesti Folkloori Instituut, Tartu

Nikodemus O, Bell S, Grīne I, Liepinš I (2005) The impact of economic, social and political factors on the landscape structure of the Vidzeme Uplands in Latvia. Landscape Urban Plan 70:57–67. doi: 10.1016/j.landurbplan.2003.10.005

Öpik E (1992) Maaviljelus (Agriculture). In: Kahk J (ed) Eesti talurahva ajalugu 1 (History of Estonian peasants, vol I). Olion, Tallinn

Paal J (1997) Eesti taimkatte kasvukohatüüpide klassifikatsioon (Estonian vegetation site type classification). Keskkonnaministeerium, Tallinn

Paal J (2007) Loodusdirektiivi elupaigatüüpide käsiraamat (Handbook of habitat types of habitat directive). Digimap OÜ, Tallinn

Pyne SJ, Andrews PL, Laven RD (1996) Introduction to wildland fire. Wiley, New York

Ratt A (1985) Mõnda maaviljeluse arengust Eestis läbi aegade (About agricultural development in Estonia). Valgus, Tallinn

Reintam LJ, Moora TH (1983) O vljanii podsečnogo zemledelija na svojstva počv (Impact of slash farming on properties of soils). In: Čelovek rastitelnost i počva (Man, vegetation and soil). Academy of Science, Tartu

Rõuk A-M (1995) Inimtegevus ja selle mõju loodusele (Human activities and their impacts to the nature). In: Raukas A (ed) Eesti Loodus (Estonian nature). Valgus and Eesti Entsüklopeediakirjastus, Tallinn

Tarkiainen Ü (2014) Aletamine maastikukujunduse- ja kultuuritegurina Põhja-Euroopas ja Eestis (Slash and burn cultivation as factor of landscape design and culture in Northern Europe and in Estonia). Tuna. Ajalookultuuri ajakiri 1:26–41

Tomson P, Bunce RGH, Sepp K (2015) The role of slash and burn cultivation in the formation of southern Estonian landscapes and implications for nature conservation. Landscape and Urban Planning 137:54–63. doi: 10.1016/j.landurbplan.2014.12.015

Vabariigi digitaalse suuremõõtkavalise mullastiku kaardi seletuskiri (2001) (Headnotes of digital large scale soil map of Estonia). Maa-amet, Tallinn. http://www.maaamet.ee/docs/kaardid/mullakaardi_seletuskiri.pdf. Accessed 25 Oct 2014

Viires A (2000) Puud ja inimesed (Trees and people). Ilmamaa, Tartu

Viro PJ (1974) Effects of forest fire on soil. In: Kozlowski TT, Ahlgren CE (eds) Fire and ecosystems. Academic Press, New York

Voionmaa V (1987) History of the Karelian Tribe in Finland-Extracts. Suomen Antropol 4:207–212

Wedin M (2003) Forest finns vs. Swedish commons. In: Berge E, Carlsson L (eds) Proceedings from a workshop on "commons: old and new", Oslo, 11–13 March 2003. Norwegian University of Science and Technology, Trondheim, pp 59–60

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Role of 19th-century rotational slash-and-burn cultivation in the development of boreal forests in southern Estonia and implications for forest management

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ABSTRACT

Slash-and-burn cultivation has been a widespread practice in Northern Europe and large portions of modern forests have developed on former slash-and-burn land. After the decline of slash-and-burn sites, forests regenerated. The aim of the present study was to compare the environmental factors and forest ground vegetation of former rotational slash-and-burn sites and continuous forest land to determine the effects of different land-use history and discuss the results in the context of conservation management. The study was based on analyses of vegetation and environmental factors of different areas, which had been mapped as slash-and-burn land and forests during the 19th century. The results demonstrated that the differences in ground vegetation between slash-and-burn sites and continuous forests are small and up to 5.2% of vegetation variability can be explained by different land use during the 19th century. There were no differences in soil characteristics among sites. The differences in vegetation could be connected to 20th century developments as sections of former slash-and-burn sites were utilised as open fields during the opening decades of the 20th century. In terms of conservation management, forests in former slash-and-burn sites must be considered as well-restored post-agricultural forests without specific features or requirements for management.

1. Introduction

Forest management and historical agricultural land use have changed environmental conditions and directly influenced plant cover. Fire has been utilised for agricultural purposes in landscapes for a long time, e.g., to prepare pastures, to prevent wildfires, or to clear land for crop cultivation. While the impacts of traditional agricultural practices in Europe, such as pasturing or haymaking, on plant diversity are well-studied, less attention has been given to the consequences of slash-and-burn cultivation. A specific feature of slash-and-burn cultivation was use of fire that caused changes in soil characteristics (Delgado-Matas, 2004; Pyne et al., 1996; Reintam and Moora, 1983; Vanha-Majamaa et al., 2007; Viro, 1974).

Slash-and-burn cultivation (swidden) was applied in ancient times, and it persisted up to the late modern period in northern Europe. Up to the early 20th century, the slash-and-burn technique was utilised in Germany, Finland, Sweden, Russia, Latvia, and Estonia (Goldhammer and Bruce, 2004; Hamilton, 1997; Jääts, et al., 2010). The practice of regularly burning young forests created in Estonia a special land category named "*buschland*" (Ligi, 1963; Meikar and Uri, 2000). The forests, mainly composed of birch and alder, were cut and burned and then used for crop cultivation for 2–5 years depending on the site's fertility. Then, the land was left fallow and used as pasture until being recolonised by trees, rotation length being 15–20 years (Ligi, 1963).

Previous studies (Raet et al., 2008; Tomson, et al., 2015) have reported that the areas that had been regularly utilised for slash-and-burn cultivation are now mostly covered by forests.

The differences between ancient and post-agricultural forest vegetation and the historical development of forests in Europe have been under discussion for a long time (Dupouey et al., 2002; Hermy et al., 1999; Hermy and Verheyen, 2007; Matuszkiewicz et al., 2013; Ohlson et al., 1997; Peterken and Game, 1984; Verheyen et al., 2003; Wulf, 2003, 2004). Lists of ancient forest plant species or ancient woodland indicators have been created for different regions (Hermy et al., 1999; Honnay et al., 1998; Schmidt et al., 2014; Wulf, 1997). Ancient forest species groups, which contain coexisting species with similar ecological demands, have recently been defined (Stefańska-Krzaczek et al., 2016). Recovery processes of forest plant communities in post-agricultural landscapes have been described by different authors, as reviewed by Flinn and Vellend (2005).

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In northern Europe, natural and old-growth forests have been given more attention (Brūmelis et al., 2011). Ohlson et al. (1997) reported a high correlation between the number of vascular plants and forest continuity, and a dependence of species richness of fungi and bryophytes on the persistence of structural elements of old-growth forests. Studies of forest landscape history are numerous (Axelsson and Östlund, 2001; Eriksson et al., 2010; Lindbladh, 1999; Linder and Östlund 1998, Östlund et al., 1997), and several studies of boreal areas have described how historical human impacts have affected forest tree composition (Axelsson and Östlund, 2001, Ericsson et al., 2005; Eriksson et al., 2010; Lindbladh and Bradshaw, 1998) or have even changed the forest type (Lindbladh, 1999).

In Estonian forests, historical continuity of forest patches and former open land has been shown to affect species composition (Paal et al., 2011). Several studies have analysed the effect of forest management and different successional stadia of forest herb layer vegetation (Aavik et al., 2009; Kohv and Liira, 2005; Meier et al., 2005; Moora et al., 2007). Most Estonian forests have been altered by forest management and the general opinion in Estonian forestry is that forests as old as 180 years have been clear-cut at least once (Etverk, 1974).

Though attracting less attention than some other historical land-use practices such as grazing and haymaking, several studies have analysed the possible effects of slash-and-burn cultivation at the landscape level. Many authors have reported an increase in the abundances of birch and alder in slash-and-burn areas, as observed in the case of regeneration after natural fires (Heikinheimo, 1915; Hokkanen, 2006; Lehtonen, 1998; Linkola, 1987; Parvieinen, 1996; Sarmela, 1987; Vasari 1992). Using pollen diagrams, Lindbladh and Bradshaw (1998) showed that original broad-leaved forests were replaced by coniferous forests after slash-and-burn cultivation in southern Sweden outfield areas. The increase of spruce in forest vegetation is attributable to a combination of climate changes and the decline of slash and burn cultivation (Bradshaw and Hannon, 1992; Lindbladh et al., 2014).

In Finland, former slash-and-burn forests are regarded as semi-natural forests by Uotila and Kouki (2005). Hokkanen (2006) described “man-made” herb-rich forests that have been created by slash-and-burn cultivation. Numerous vascular plant species have been noted as typically present at former slash-and-burn sites (Myllyntaus et al., 2002).

In Estonia, the prevailing opinion is that slash-and-burn cultivation has caused considerable impoverishment of vegetation. Laasimer (1958) suggested on the basis of pollen data that soil depletion caused by regular slash-and-burn cultivation, followed by permanent cultivation, led to the formation of dry oligotrophic pine forests and *Oxalis* spruce forests. Recent Estonian studies have asserted that species-poor spruce forests could grow in former slash-and-burn sites (Paal, 1997; Rõuk, 1995). Tomson et al. (2016) analysed the forest composition in former slash-and-burn sites in southern Estonia using the State Forest Management Database (FMD) and discovered that the most common was the *Oxalis* forest type.

The aim of the present study was to analyse the environmental and vegetational differences between former rotational slash-and-burn sites, and sites which have been continuous forest land since the 19th century. Legacies of historical land use and former rotational slash-and-burn fields are discussed with respect to biodiversity protection and conservation management.

2. Material and methods

2.1. Environmental conditions

The study was carried out in southern Estonia in Valga and Võru counties, in the Boreal Region as defined by Metzger et al. (2005). The climate in the region is moderately continental; the average temperature is −5 °C in winter and 16 °C in summer. The average annual precipitation is approximately 700 mm (Tarand et al., 2013). The sandy and loamy soils are mainly acidic and overlie various Quaternary sediment moraines, covering the Devonian bedrock (Astover et al., 2012). The region is mainly hilly, with moraine kames.

2.2. Selection of study sites

Field work was carried out during the summer months in 2014 and 2015 in five protected areas: Karula National Park (47 forest stands), Pikkjärve (three forest stands), Paganamaa Landscape Protection Area (eight forest stands), Pähni Nature Protection Area (three forest stands) and Haanja Nature Park (19 forest stands; Fig.1).

Former slash-and-burn sites (*buschlands*) and continuous forest land were identified using 19th-century maps, including the maps of Karula (1867), Vana-Antsla (1871–1872), Boose (1871–1872), Haanja (1851), Vana-Roosa manor (1886), Krabi manors (1878), and different farm maps (Appendix A). Historical maps were geo-referenced and raster maps were compared with digital layers from the FMD (Environment Agency, 2017) to locate suitable areas for a vegetation survey of forest patches. Stands older than 90 years were preselected to ensure that the ground vegetation was representative. Forest patch sizes greater than 0.5 ha were preferred. Various forest types located in former *buschlands* were selected for vegetation analyses: of these study areas 31 (68.9%) were *Oxalis* main type, 10 (22.2%) were transitional *Oxalis-Vaccinium myrtillus* subtype forests, two (4.4%) were *Oxalis-Vaccinium vitis-idaea* subtype, and two (4.4%) belonged to *Hepatica* type, according to FMD. Based on a previous study (Tomson et al., 2016) the *Oxalis* forest site type was considered typical of slash and burn cultivation sites. Therefore, *Oxalis* type stands, which had been mapped as forest during the 19th century, were selected for comparison. The stands with fresh signs of forest cutting were excluded to avoid any influence of recent human impact. Of the 80 observed forest stands, 45 were former *buschlands*, and 35 were forest land stands. In most observed forest stands, five vegetation plots were examined. The slash and burn cultivation areas were named “*buschland*” in the 19th- century maps; therefore, the forests located in the former slash-and-burn sites are named as *buschlands* in the present study. The stands located in areas mapped as forest in the 19th century are hereafter named former forest.

2.3. Field studies

For vegetation surveys, the methodology of Bunce and Shaw (1973) was applied. Plots of 200 m^2 were utilised in the present study and were selected randomly within the preselected forest stands. The abundances of trees regeneration and of bushes were recorded by species. The general coverage of the bryophyte layer and presence of species were also recorded. Unknown bryophytes were collected and identified by staff at the Herbaria of Estonian University of Life Sciences. Vascular plants were identified based on Leht (2010), and bryophytes were identified based on Ingerpuu and Vellak (1998). In the observed stands, 151 species of vascular plants (Appendix B) and 51 species of bryophytes (Appendix C) were recorded, with 92 vascular plant species present in more than 5% of stands. In the herbaceous layer 85 vascular plant species were registered in more than 5% of stands.

The diameter of trees measured at a height of 1.3 ms was recorded by species. In addition, in every forest stand, the effect of former human impact was estimated, using the timescale factor (late: 5 years, medium: 5–20 years, and old: greater than 30 years) and strength (missing, weak, medium, and strong effect). The types of human impact were previous fellings, roads, hiking trails, traces of former resin collections, and effect of being adjacent to clear-cut areas. In subsequent analyses, the

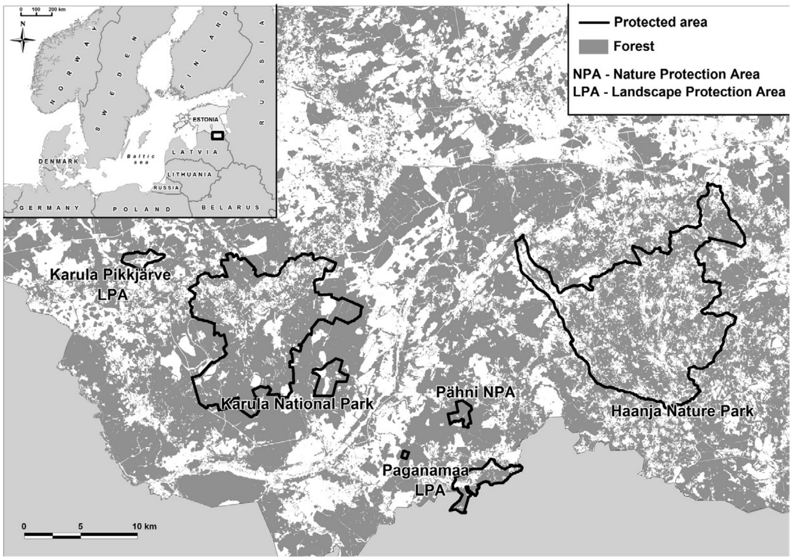

Fig. 1. Location of study areas.

human impact from every period and type were summed to obtain one general index.

The position of the studied forest stands in the landscape was recorded and expressed as isolated stands in agricultural land, edges of forest patches or large blocks of forest. The location of sample plots was characterised by location in the relief (flat land, the top of hills, the base of hill, hill slope) and in the landscape (isolated, forest edge, forest massive). The numbers of fallen dead tree-trunks on the ground, stumps, and uprooted trees were recorded. Landscape elements connected with former slash-and-burn cultivation, such as large relict trees, field banks, and excavated pits (for storing turnips over winter) were recorded.

In every forest stand, soil characteristics were recorded, i.e., soil texture, thickness of litter, and humus layer. The soil samples were collected from the humus layer and under it for laboratory analyses.

2.4. Data processing

The data from FMD were utilised to describe the stand areas, dominant tree species, dominant tree species ages, and forest site type for the former slash-and-burn sites. Three of the initially selected stands were divided into two because the sample plots did not have uniform environmental characteristics, so in total 83 sites were used, with an average 4.8 sample plots (2–8) per site.

As light conditions are heavily influenced by tree cover and may differ according to tree species, the basal areas of trees were obtained to include the effects of different tree species as factors. Additionally, the basal area of young trees of genus *Picea*, equal to or less than 5 cm in diameter, were calculated to characterise poor light conditions under the young trees. The basal area of dead standing trees was also calculated.

The soil types of the forest stands were identified using the digital Estonian Soil Map (Estonian Land Board, 2017b).

To analyse the subsequent development of former slash-and-burn sites, a one-verst topographical map from 1912 to 1922 was used, which was available from the Estonian Land Board Web Map Server Historical Map Application (Estonian Land Board, 2017b). The land cover types of these maps were grouped into three classes: open (fields and grasslands), transitional (shrubs and areas with sparse trees), and forests.

In several stands of the former forests group, field banks were discovered during the field work, which are clear signs of former cultivation. This occurrence indicated that the temporal aspect of slash-and-burn effects could be considered. Therefore, the former forests group was divided into two subgroups: former forests without cultivation signs were named "continuous forests" and areas that were mapped as forest during the 19th century but had obvious traces of cultivation were named "older *buschlands*". Therefore, three groups in total were formed that characterised the time gradient: recent *buschlands* (mapped as *buschland* during the 19th century, n = 47), older *buschlands* (n = 11) and continuous forests (n = 25).

Because soil and forest characteristics were recorded by FMD stand level and because the number of plots was not the same in each stand, the final database was built up by site level. The data measured at single plots were averaged by site. This meant that some information from single plots was lost; however, this decreased the random noise caused by the random choice of plots (the plots with extreme values have less of an effect on the results) and repeated measures, which are problematic in complex multivariate analyses, were avoided. Before averaging, the coverage of vascular plant species with coverage less than 2.5% was set to 1%. In addition, one dataset with average plant coverage and another dataset with presence of plants were created (a plant species was considered present if it was present in at least one plot of the site). The recorded non-numerical environmental characteristics were converted to gradients. Soil types were ordered by the gradient of soil based on the Lõhmus' forest ordination scheme (Asi et al., 2004). Forest productivity was used to place Delluvial soils into the gradient (Astover et al., 2012) at the same position as Haplic Albeluvisols.

The following soil properties of the humus horizon and the horizon under the humus were measured in the laboratory: pH_{KCl}, the total nitrogen (N; Kjeldahl digestion method (van Reeuwijk, 2002)), organic C concentration (Tjurin method (Vorobyova, 1998)) and soil specific surface area (m^2/g; obtained by the water steam adsorption method) (Bigham, 1996). The list environmental variables and soil properties, with short descriptions and ranges of values, is presented in Appendix D.

For additional analyses, the recorded vascular plant species were grouped according to their ecological preferences (ancient forest indicators by Wulf (2003), affinities for human impact (antropophytes, apophytes, hemeradiaphores, and hemeraphobes; Kukk (1999) and dispersal types (autochores, amemochores, zoochores, myrmecochores, hydrochores, and others).

2.5. Statistical analyses

All statistical analyses were performed with R 3.2.3 software and results were considered statistically significant at $p \leq 0.05$.

The permutation analysis of variance (ANOVA) with the function 'oneway_test' in R package 'coin' was applied to compare the environmental factors as well as the coverage of herbaceous plant species and bryophytes in groups "*buschlands"* and "former forests" and in groups "recent *buschlands*", "older *buschlands"* and "continuous forest". The same methodology was utilised to compare sites grouped by land cover types at the beginning of the 20th century and by three regions (1) Haanja Nature Park, (2) Karula National Park and Karula Pikkjärve Landscape Protected area, (3) Pähni Nature Protection Area and Paganamaa Landscape Protection Area. The presence data of herbaceous plants were analysed using the Fisher exact test. For analyses of plants and bryophytes, the Bonferroni-Holm correction for multiple testing was applied using the R function 'p.adjust'.

Several multivariate analysis methods were then applied. Principal component analysis (PCA) was used to discover basic patterns in vegetation coverage and to study the relationship of these patterns to environmental factors. The multi-response permutation procedure (MRPP) and permutational multivariate ANOVA (perMANOVA) were used to test the difference in vegetation coverage between land-use groups. Finally, the between-groups principal component analysis (BGPCA) *alias* principal component analysis with respect to instrumental variables was applied to discover patterns in vegetation coverage distinguishing different land-use histories. Only the data concerning herbaceous layer vascular plant species in more than 5% of stands were included in multivariate analyses. PCA and BGPCA were performed with the functions 'dudi.pca' and 'bca' in R package 'ade4', and MRPP and perMANOVA were performed with the functions 'mrpp' and 'anosim' in R package 'vegan'.

Table 1
Mean (standard deviation) values of landscape and soil characteristics with statistically significant ($p < .05$) differences between different types of areas and p-values according to one-way analysis of variance using permutation test. The short descriptions and ranges of values are presented in Appendix D.

Variable	Recent *buschland*	Older *buschland*	Continuous forest	p-Value
Location	2.5 (0.58)	2.9 (0.30)	2.9 (0.28)	0.001
Field banks	1.11 (0.80)	1.14 (1.22)	0.00 (0.00)	< 0.001
Turnip pits	0.301 (0.564)	0.176 (0.336)	0.016 (0.055)	0.035
Age (year)	112.7 (15.9)	133.1 (27.3)	130.3 (20.6)	< 0.001
Area (ha)	2.09 (1.83)	1.83 (1.20)	3.92 (3.44)	0.005
Large trees	1.15 (0.84)	0.62 (0.89)	0.14 (0.32)	< 0.001
Litter (cm)	4.79 (2.26)	6.55 (2.58)	6.12 (2.42)	0.016

3. Results

3.1. Comparison of environmental factors

The permutation tests comparing environmental factors in recent and older *buschlands* and continuous forest revealed only a few statistically significant differences (Table 1). Continuous forest stands tended to be larger, older and located more distantly from the forest boundary than the other two groups and had fewer large relict trees and traces of former turnip pits. The age of dominant trees was higher in both continuous forest and the older *buschland* areas. The stand areas were largest in continuous forest sites. The recent *buschlands* had thinner litter layers. In addition, the recent *buschland* areas tended to have deeper humus layers; however, these differences were not statistically significant (on average 15.1 cm in recent *buschlands* versus 12.1 and 12.6 cm in older *buschlands* and continuous forests, respectively, $p = .077$). The dead standing trees, fallen dead trees, stumps and uprooted trees were not significantly different within groups. Also the estimated extent of damage by wild boars to the ground vegetation did not differ.

The comparison of the two initial groups of study sites (*buschlands* versus former forests) did not reveal any additional differences in environmental factors. This is because having similar environmental features was a precondition in selecting stands for field work. However, the humus layer was recorded as being thicker in *buschlands* than in former forests (15.1 versus 12.1, respectively, $p = .033$). There was no difference in pH_{KCl}, N%, and C% among the three groups of areas (all $p > 0.4$). The C-N ratio was the lowest in recent *buschlands* (11.4), followed by older *buschlands* and continuous forests (14.2 and 18.6, respectively); this difference was not statistically significant ($p = .176$).

3.2. Comparison of ground vegetation

Out of 85 regular (recorded in more than 5% of stands) herbaceous layer vascular plant species, 13 showed a statistically significant different coverage among different forest groups (Appendix B). Five of these species (*Crepis paludosa*, *Dryopteris expansa*, *Equisetum sylvaticum Melampyrum nemorosa* and *Melampyrum pratense*) had higher coverage in continuous forests, three (*Convallaria majalis*, *Galeopsis tetrahit* and *Polygonatum odoratum*) had higher coverage in both continuous forests and older *buschlands*, three (*Chelidonium majus*, *Circaea alpine* and *Vaccinium vitis-ideaea*) in older *buschlands*, and two (seedlings of *Sorbus aucuparia* and *Populus tremula*) in recent *buschlands*. However, after applying the correction for multiple testing, none of these differences remained statistically significant.

The average number of species in each site was almost the same for all three groups of study sites (average 17.6, 18.3, and 18.0 species in

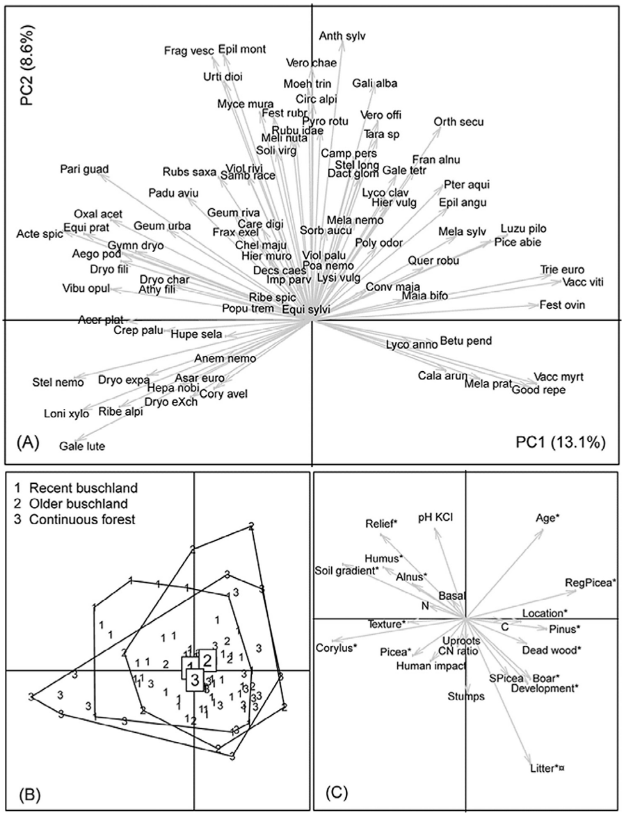

Fig. 2. Results of principal component (PC) analysis of plant species found in at least 5% of study sites: (A) lengths and directions of arrows denote the weights of plant species concerning the first two principal components; (B) location of study sites on the plane of the first two principal components, each site is marked with its type number and centroids of different groups are denoted with the numbers in larger font in boxes; (C) correlations of selected landscape and soil characteristics with the first two principal components, statistically significant ($p < .05$) correlations with PC1 and PC2 are denoted with * and ¤, respectively.

recent *buschlands*, older *buschlands*, and in continuous forests, respectively, $p = .86$). There were no statistically significant differences in species richness of examined ecological groups except in groups based on dispersal types, with myrmecochores being more common in older *buschlands* and continuous forests (1.27 and 1.12 species, respectively) and less common in recent *buschlands* (0.79 species, $p = .030$). The presence of ancient forest indicators did not differ among continuous forests and both types of *buschland*, and the number of hemeraphobes was not significantly different among the observed groups. The comparison of the two initial groups of study sites (*buschlands* with former forests) did not reveal additional statistically significant differences in coverage of single species or in species richness of ecological groups. The analyses of maximum coverage of vegetation did not reveal any further statistically significant differences among the three groups of study sites.

The comparison of presence of vascular plants revealed a greater number (18) of differences. Statistically significant differences ($p < .05$) in presence data were found for the following species in recent *buschlands*, older *buschlands*, and continuous forests: *Acer platanoides* (0.87, 0.64, and 0.55, respectively), *Alnus incana* (0.32, 0.27, and 0.04, respectively), *Calamagrostis arundinacea* (0.30, 0.64, and 0.72, respectively), *Chelidonium majus* (0.09, 0.27, and 0.00, respectively), *Convallaria majalis* (0.19, 0.36, and 0.60, respectively), *Crepis paludosa* (0.04, 0.18, and 0.24, respectively), *Daphne mezereum* (0.00, 0.09, and 0.16, respectively), *Dryopteris expansa* (0.02, 0.00, and 0.20, respectively), *Fragaria vesca* (0.93, 0.82, and 0.72, respectively), *Fraxinus excelsior* (0.30, 0.09, and 0.04, respectively), *Galeopsis tetrahit* (0.15, 0.36, and 0.44, respectively), *Lysimachia vulgaris* (0.04, 0.09, and 0.24, respectively), *Melampyrum nemorosum* (0.00, 0.09, and 0.16, respectively), *Polygonatum odoratum* (0.04, 0.09, and 0.24, respectively), *Populus tremula* (0.70, 0.18, and 0.28, respectively), *Padus avium* (0.28, 0.09, and 0.00, respectively), *Quercus robur* (0.96, 0.91, and 0.64, respectively), and *Salix caprea* (0.02, 0.18, and 0.16, respectively). After applying the correction for multiple testing, only differences in the presence of *Populus tremula* remained statistically significant ($p = .027$).

Six species of bryophytes showed apparent differences among the three groups of study areas. *Brachythecium oedipodium*, *Eurhynchium angustirete*, *Plagiomnium affine*, and *Rhytidiadelphus triquetrus* were more common in recent *buschlands*, whereas *Plagiochila asplenioides* and *Polytrichum formosum* were more common in continuous forests. After applying the correction for multiple testing, only differences in the presence of *Brachythecium oedipodium* remained statistically significant.

3.3. Multivariate relationships among ground vegetation, environmental factors, and land use

The PCA revealed that 21.7% of the total variability of coverage of regular herbaceous layer vascular plant species could be described by the first two factors. The first factor mainly distinguished the species that preferred shaded environments in fresh and less acidic soils, such as *Stellaria nemorum*, *Actaea spicata*, *Lonicera xylosteum*, and *Galeobdolon luteum*, from others (*Vaccinium vitis-idaea*, *Trientalis europaea*, *Festuca ovina*, and *Luzula pilosa*; Fig. 2A). The second factor is more related to human impact, i.e., the species less sensitive to human impact are located on the upper side of Fig. 2A (*Epilobium montanum*, *Veronica chamaedrys*, *Taraxacum* sp., *Urtica dioica*). However, these species patterns are not related to the analysed land-use history (Fig. 2B) because the ANOVA comparing the values of the first two principal components in areas with different land-use histories showed no statistically significant differences in the case of trees or in the two groups (all p-values > 0.3).

The correlation analysis of principal components and environmental factors (Fig. 2C) showed a statistically significant negative correlation between the first principal component (PC1) and summed basal area of *Corylus avellana* and *Picea abies*, which reflects poor light conditions. PC1 was also negatively correlated with soil gradient, soil texture, thickness of humus layer, and relief (the species on the left side of Fig. 2A are more dominant in kames that have loamy and more fertile soils). PC1 was positively correlated with ages of the dominant trees, summed basal area of pine, litter thickness, effect of wild boars, average number of fallen dead tree trunks, presence of dense groups of spruce regeneration, distance from forest boundary, and land cover in 1912–1922. The species on the right side of Fig. 2A are more dominant in areas that were forested more than a century ago and are currently located in forest massive where there are older and bigger conifers growing and where the effect of boars is greater. The second principal component (PC2) was significantly and negatively correlated only with litter thickness, and slightly positively but not significantly correlated with the age of trees and relief (the species on the upper side of Fig. 2A tend to be more dominant on glacial kames that have older trees and lower thickness of litter layer).

The comparison of regular herbaceous plant species coverage in areas with different land-use histories using MRPP revealed that the within-group homogeneity, compared to the random expectation, approached statistical significance ($A = 0.0051$, $p = .109$ and $A = 0.0078$, $p = .017$, in the case of three- and two-group comparisons, respectively). The perMANOVA showed significant differences among areas with different land-use histories ($p = .027$); however, only 4.1% of plant coverage variability was accounted for by the differences in the three groups.

Comparing the presence of plant species, including trees, regeneration, bushes, and bryophytes, the results were similar after applying MRPP (in the case of three groups $A = 0.0095$, $p = .001$ and in the case of two groups $A = 0.0096$ and $p = .004$). The perMANOVA showed significant differences in both the three- and two-group comparisons (accounted variability 5.2%, $p = .004$, and 4.1%, $p = .004$, respectively).

The comparison of land cover types according to maps from 1912 to 1922 (open versus transitional versus forest) revealed statistically significant and slightly stronger effects on plant coverage (MRPP: $A = 0.0115$, $p = .012$; perMANOVA: accounted variability 6.6%, $p = .001$). Analyses of the presence data of plant species revealed similar results (MRPP: $A = 0.0118$, $p = .001$; perMANOVA: accounted variability 7.2%, $p = .002$).

The vegetation differences were the clearest between regions (plant coverage analyses MRPP: $A = 0.0458$, $p = .001$; perMANOVA: 11.7%, $p = .001$; plant presence analyses MRPP: $A = 0.0307$, $p = .001$: perMANOVA: 13.6%, $p = .001$).

The BGPCA confirmed the results of the MRPP and perMANOVA in being able to separate the three groups of sites with different land-use histories (Fig. 3B). However, statistically significant differences were only reported in the values of the first component, distinguishing areas in the horizontal direction ($p < .001$) and accounting for 69.4% of the plant coverage variability explained by the different land-use histories. The values of the second component, distinguishing areas in the vertical direction (mainly distinguishing older *buschlands*), were not statistically significantly different ($p = 0.65$) and accounted for 30.6% of the plant coverage variability explained by the different land-use histories. The overall effect of land-use history on current plant coverage was statistically significant ($p = 0.005$) but had little importance, accounting for only 3.8% of the total plant coverage variability between sites. However, irrespective of the small effect, the BGPCA still allowed the identification, in areas with different land-use histories, of frequently observed vegetation patterns. These results are similar to the results of the univariate analyses. Species located on the left side of Fig. 3A (especially *Sorbus aucuparia, Quercus robur, Acer platanoides*, and *Populus tremula*) were more dominant in recent *buschlands*, whereas the species located on the right side of Fig. 3A (*Galeopsis tetrahit, Convallaria majalis, Crepis paludosa, Calamagrostis arundinacea*, and *Lysimachia vulgaris*) were more common in continuous forests. Species located in the upper portion of Fig. 3A (especially *Chelidonium majus* and *Circaea alpina*) were common in older *buschlands*. The correlations with other environmental factors (Fig. 3C) revealed that plant species that were more dominant in areas classified as recent *buschlands* grow in hilly areas, which have better soils with higher nitrogen content and a thicker humus layer, and have been subjected to greater human impact. The plant species that are more dominant in areas classified as continuous forests (on the positive side of the first axis) grow in areas that were forested more than a century ago and that are currently located deep in the forest with older trees and a thicker litter layer. The plant species more common in areas classified as older *buschlands* are positively related to older trees, summed basal area of pine, and fallen dead tree trunks, and negatively related to human impact and soil texture, humus layer thickness, soil fertility, number of stumps, and summed basal area of *Corylus*.

4. Discussion

4.1. The effects of land use and environmental factors

In the present study, only small vegetation differences between former rotational slash-and-burn sites and continuous forests were

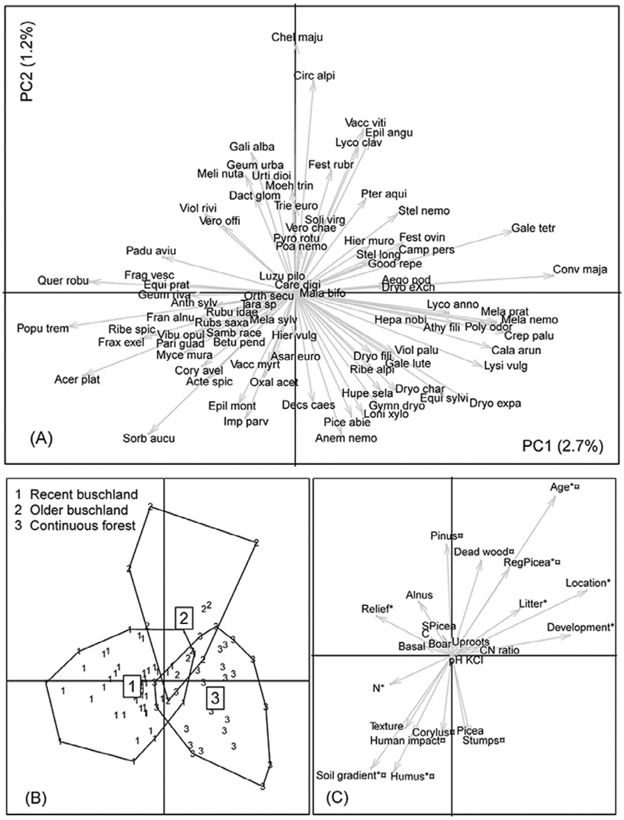

Fig. 3. Results of between-group principal component analysis (BGPCA) of plant species found in at least 5% of study sites: (A) lengths and directions of arrows denote the weights of plant species concerning the components separating the areas with different land use histories (3.9% of total variance of plant species coverage was explained by the factor land use); (B) location of study areas on the plane of plant species patterns, each site is marked with its type number and centroids of different groups are denoted with the numbers in larger font in boxes; (C) correlations of selected landscape and soil characteristics with the discovered components, statistically significant ($p < .05$) correlations with the first and the second component are denoted with * and ¤, respectively.

detected, as only 3.8–5.2% (depending on the analysis method) of the overall vegetation variability between sites could be explained by the 19th-century land use.

The environmental factors most strongly related to plant communities were soil properties and light conditions. The effect of basal areas of *Picea abies* and *Corylus avellana* is connected to their ability to shade the ground, leading to poor light conditions for understorey vegetation.

The pH of the soil humus layer did not show significant differences between sites with different land-use histories. There was no evidence of transition of soil acidity among recent *buschlands*, older *buschlands* and forests. This was confirmed by the vegetation surveys, which did not indicate whether soils in the former slash-and-burn areas were more or less acidic than the soils in the forest land. More than a century has passed since the decline of slash-and-burn cultivation in this region (Jääts et al., 2010), which could have been sufficient for soil pH to recover, as observed by Delgado-Matas (2004) and Viro (1974). The present study has shown that recovery of soil pH is also possible in areas subsequently used for arable cultivation. No differences were found in other observed soil characteristics; therefore, changes to soil properties due to regular slash and burn cultivation cannot be inferred. From the BGPCA it was revealed that the recent *buschlands*, with their typical vegetation, tended to be located in more fertile soils; however, this might simply be due to the selection of better lands for cultivation.

Traditionally, the *buschlands* were scattered among other land use plots or located at the edges of farmland (Tomson, 2007). This might be why the former *buschlands* are correlated more with forest edges than continuous forests. Average tree cover in *buschlands* is younger because this group contains sites that were used as arable fields after the end of slash-and-burn cultivation; forest cover only started to grow there after abandonment of these areas at the beginning of the 20th century. The forest in the sites mapped as forest in the 19th century were probably managed using clearcuttings by that time, so the dominant tree layer there today is less than 200 years old.

4.2. Vegetation differences

Fire can impact ground layer vegetation in different ways: destroying the vegetation, creating favourable open conditions for germination of new species, opening the canopy and improving light conditions, and changing the soil properties. The first vascular plants in a burned area are easily spreading pioneer species. The succession and recovery of original vegetation is rapid after burning, and several species typical of early successional stages after fire are common (Ruokolainen and Salo, 2009). Plants which are heat tolerant or have deep rhizomes or seeds can survive and regenerate after fire, as both regeneration and colonisation occur after fire (Hekkala et al., 2014; Ruokolainen and Salo, 2009; Schimmel and Granström, 1996).

The management cycle of *buschlands* did not promote natural post-fire succession because the fire was followed by cultivation for 3–5 years, after which the fallow fields were often grazed (Tomson et al., 2015). The assumption cannot be justified, that, in the former slash-and-burn sites, higher coverage and presence of pioneer, ruderal, and meadow species are due to the seed bank. The effect of fire on vegetation was expected to reveal itself through soil changes and was not expected to be related to post-fire succession. However, no such differences were reported in the present study. Additionally, specific fire-dependent species such as *Pulsatilla patens*, *Pulsatilla pratensis*, *Geranium bohemicum*, etc. (Kalamees et al., 2012; Reier, et al., 2005) were not found either in *buschlands* or in continuous forest areas.

There are numerous studies describing the impacts of fire on the forest tree layer composition, as pioneer species in burned areas include pine, birch, alder and aspen (Axelson and Östlund, 2001; Hekkala et al., 2014; Hellberg et al., 2009; Parviainen, 1996; Viro, 1974). Deciduous pioneer tree species have also been associated with slash-and-burn areas (Heikinheimo, 1915; Hokkanen, 2006; Lehtonen 1998; Lindbladh and Bradshaw 1998; Linkola, 1987; Sarmela, 1987; Vasari, 1992). Alder was present in a greater number of sites in *buschlands*, as this species is typical in the overgrown fields in the region. Birch was not more common in the former slash-and-burn sites. The seedlings of deciduous trees (*Populus tremula*, *Sorbus aucuparia*, *Quercus robur*, *Acer platanoides*) were found more frequently in *buschlands* and could be remnants from the successional period after slash-and-burn cultivation. The more frequent occurrence of seedlings may also be associated with the fact that *buschlands* are more closely connected with forest edges. The increase of spruce, observed in abandoned slash and burn areas in Sweden (Lindbladh et al., 2014), was not registered.

In the Koli area of Finland, edaphically demanding species still occur on what were slash-and-burn sites and Hokkanen (2006) therefore proposed that herb rich forests can be expected to develop on former burnt sites. This outcome was not observed in the present study, with the average numbers of species in *buschland* sites not being different from those in the former forest sites.

Differences between Finnish and Estonian studies can be explained by the decline of slash-and-burn cultivation having been earlier in Estonia than in Eastern Finland i.e., in the 19th century rather than in the 1940s (Lovén and Äänismaa, 2004). The effect of fire on soil characteristics decreases with time. In addition, processes of nutrient circulation and decomposition are much slower at higher latitudes (Bonan and Shugart, 1989); therefore, forest recovery processes in eastern Finland may take longer than in Estonia.

In addition, in the present study, some species typically found in slash-and-burn cultivation sites in Finland *Rubus saxatilis* and *Oxalis acetosella*, were equally abundant in both *buschlands* and former or continuous forests. Only *Fragaria vesca* was present in a greater number of *buschland* sites.

In Estonia, the rotational slash-and-burn cultivation that involved ploughing and phases of grassland and young deciduous tree cover (Meikar and Uri, 2000; Tomson et al., 2015) lasted for centuries. Therefore, the maintenance of seed banks or the regenerative parts of forest plants is less likely than in the *Huuhta*-cultivation in Finland. There, the fields were used for one year after burning without ploughing and then left to grow the next generation of coniferous forests (Sarmela, 1987). The recovery of forest vegetation in Estonian slash-and-burn sites is thus more dependent on colonisation. During the 19th century, the majority (33) of the observed *buschlands* were sparsely situated among agricultural lands and 14 were bordered by natural habitats. The lower species diversity of myrmecochores in *buschlands* reflects these constraints. The diversity of hemeraphobes and hemeradiaphores did not show differences. We have found numerous species, designated ancient forest indicators in Central Europe (Wulf, 2003), to be present in large numbers in previous slash-and-burn sites, and differences were not found between *buschlands* and continuous forests. For most European countries, the threshold dates for the definition of woodland as ancient are earlier (Hermy and Verheyen, 2007) than the dates for commencement of forest recovery in former *buschlands*. For the majority of forest species, the time since agricultural use of *buschlands* has been sufficient for colonisation. In continuous forests, there were several species of hemeraphobes (*Carex brunnescens, Chimaphila umbellata*, *Milium effusum*, *Carex vaginata, Carex rhizina*, *Pyrola minor*, *Sanicula europaea* and *Vicia sepium*) that were not present in *buschlands*; however, these species grew in only 1–3 forest sites and therefore cannot be considered as typical to continuous forest land. These results support the conclusion (Schmidt et al., 2014), that ancient forest indicator species are not clearly distinguishable in the case of Nordic coniferous forests.

In this study, the forests in former slash-and-burn areas are of diverse forest site types and would therefore be expected to have considerable species diversity overall, but when compared with the former forest stands (which were all of *Oxalis* type) this was not found to be the case. This supports the suggestion that the vegetation in former slash-and-burn sites has still not completely recovered.

Both forests and *buschlands* were affected by previous selective cuttings. Forest management affects the ground layer vegetation by changing light conditions, which occurs particularly in *Oxalis* forests (Kohv et al., 2013). Liira et al. (2007) have shown that forest management can increase the herb layer species richness and the presence of graminoids and ruderals. Therefore, forest management can unify the species composition of differently developed forests. However, Żmihorski (2011) argued that the differences in vegetation of recent and ancient forests are still observable even after clear cuttings.

Paal et al. (2011) declared that the vegetation composition is connected with the land cover and location of forest patches at the beginning of the 20th century. The present study demonstrated that variability connected with land cover during 1912–1922 in Russian one-verst maps is greater than the variability connected with slash-and-burn cultivation (7.2–7.4% versus 4.1–5.2%, respectively, in perMANOVA analyses). This implies that subsequent land use is slightly more important than preceding slash-and-burn cultivation. Approximately 130 years have passed since the decline of slash-and-burn cultivation in the vicinity of the studied areas (Jääts et al., 2010), although the exact number of years of abandonment for each plot probably varies. Many plots were probably utilised as arable field or grassland for shorter or longer periods after abandonment. The differences in vegetation of observed slash-and-burn groups may reflect differences in their later development. The former slash-and-burn forests in Estonia may be regarded as nearly recovered post-agricultural forests.

The study supports the general finding (Laasimer, 1958; Paal, 1997; Rõuk, 1995), that mesic *Oxalis* forests are common in Estonian slash-and-burn sites. Dry oligotrophic pine forests as suggested by Laasimer (1958) were not registered. The occurrence of species-poor forests in former slash-and-burn sites is probably due to delayed forest recovery subsequent to slash and burn cultivation. As the analysed sites were used for slash-and- burn cultivation at a range of different times it is reasonable to conclude rotational slash-and-burn cultivation has had less of an impact than previously assumed.

The dominant tree species from the FMD were more commonly pine than the spruce that is considered to be typical of *Oxalis* forests (Lõhmus, 2004). In understorey and regeneration the spruce is more abundant. In the Haanja region, the most common dominant tree species was spruce due to more fertile soils, and pine was only dominant in some former *buschlands*. The frequent occurrence of pine in the upper layer may be connected with forest recovery in open lands, as is currently observed in abandoned agricultural land in Estonia. Additionally, the prevalence of grown-up pines, especially in continuous forest land, may be the result of plantations, which became widespread during the 19th century (Etverk, 1974). Karula, Vana-Roosa, and Krabi manors belonged to landlords during the 19th century, whereas Haanja was state-owned. Therefore, it is likely that in Haanja the forests were not as well managed as in the private manors, and forest regeneration there was natural as opposed to the other manors, where plantations were used.

It is likely that the forests classified as continuous forest in the present study were burned for cultivation in earlier times; however, this has not left visible traces in the landscape and the cultivation may not have been intensive. Therefore, it is not possible to exclude slash-and-burn cultivation as having had some influence on the formation of vegetation in the continuous forest group.

Forest history studies from Scandinavian countries have demonstrated the effect on the forest vegetation of climate changes in combination with human activities (Bolte et al., 2010; Bradshaw and Hannon, 1992; Cowling et al., 2001; Sköld et al., 2010) over recent millennia. In Estonia only pollen studies for this period are available, and these show the effects of climate changes on tree cover in the first half of the Late Holocene. At the end of Holocene, human impact in Estonia coincided with climate cooling, promoting the increase of the boreal tree species *Betula, Salix* and *Pinus* (Reitalu et al., 2013). The impact on Estonian forest composition of the cooler climate in the second part of the last millennium is overshadowed by that of wars and epidemics (Sillasoo et al., 2009). As in Estonia the most common tree species are not at their distribution border, climate cooling did not had such a strong effect on tree cover composition as it did in Scandinavia. The warming after the Little Ice Age of the second half of the 19th century coincided with expansion of coniferous plantations. Pollen analyses from lakes in study areas in Karula National Park (Poska et al., 2017) and Haanja Nature Park (Niinemets and Saarse, 2009) do not reveal vegetation changes that could be attributed to slash and burn forests or to continuous forests connected with climate changes.

5. Implications for conservation and management

In Karula National Park, more than half of the old forests in former rotational slash-and-burn sites have been designated as Natura 2000 Habitats (Tomson et al., 2015). These were mainly designated Western Taiga type because of their relatively natural structure, with many rotten logs and dead trees. In spite of this obvious biodiversity value, it is still to be determined how natural is the vegetation of these forests.

The results of the present study show that in Estonia, unlike in Finland, the forests in former rotational slash-and-burn sites cannot be regarded as semi-natural habitats with specific vegetation. Considered as post-agricultural or recent forests, these forests show a strong recovery of vegetation in comparison with the areas under the forest in 19th century. Therefore, it must be questioned whether there is any need for special conservation management activities, such as prescribed burning.

Former *buschlands* and forests in areas mapped as forest during the 19th century are comparable, both by their elements of old-growth forests and vegetation and require maintenance in protected areas. In addition, the results suggest that younger secondary forests that regenerated during the 20th century in former agricultural land (Tomson et al., 2015) could eventually develop into proper forest habitats without special conservation management efforts. This situation may change in response to climate change. In Estonian forests the expectation is a spread of deciduous trees and increased effects of forest disturbances (Bioclim, 2015; Lindner et al., 2014). As the systematic management of mesic coniferous forest has caused the depletion of forest diversity (Lõhmus et al., 2005), in the immediate future climate changes could increase the species diversity and amount of coarse wood debris. As former slash and burn forest already have more deciduous seedlings, the spread of deciduous trees could more rapid in former *buschlands*. In the longer perspective the coniferous trees could be replaced by deciduous trees. Monitoring is therefore necessary and management strategy should be re-evaluated accordinglyly.

6. Conclusions

Environmental factors, especially light and soil conditions, appeared to be more important for vegetation variability than a history of rotational slash-and-burn cultivation. The former rotational slash-and-burn cultivation sites and forests, growing since the 19th century, are associated with different locations, the former being more connected with forest edges and hilly landscape than the latter.

Several differences were found between ground vegetation of former rotational slash-and-burn cultivation sites and forests in areas mapped as forest during the 19th century. Ancient forest indicator species were equally present in former slash-and-burn sites and continuous forests. The myrmecochores were less common in former slash-and-burn sites owing to dispersal delay. Comparing the land cover of the same sites at the beginning of the 20th century, greater differences were reported among previous open, transitional, and afforested areas.

Lasting changes in soil properties were not confirmed, suggesting the soil has recovered from the effects of slash-and-burn cultivation. Therefore, it is more appropriate to consider the former rotational slash-and-burn cultivation sites as post-agricultural forests in Estonia, with no specific effects of fire yet determined. In general, field investigations should be accompanied by the use of other sources, such as historic maps. It is possible that forest vegetation has also been influenced by slash-and-burn cultivation of several centuries ago, whose signs have not been detectable, and the situation in neighbouring countries may well be different. The results of the current study support the opinion that former rotational slash-and-burn cultivation sites have contributed to the development of species-poor *Oxalis* forests. In Estonia these forests have recovered remarkably after the cultivation phase and could serve as a component of the Natura 2000 network.

Acknowledgements

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Appendix A

Historical maps utilised during the present study.

	Mapped area	Map name	Year drawn	Scale	Reference code of the Estonian National Archive	Protected area
1	Vana-Antsla manor	Charte von dem privaten Gute Alt-Anzen	1871–72	1:20,800	EAA.3724.4.1838	Karula
2	Boose manor	Charte von dem privaten Gute Bosenhof	1871–72	1:18,081	EAA.3724.4.1867	Karula
3	Karula manor	Situations Charte von dem Gute Carolen	1867	1:20,800	EAA.3724.5.2803	Karula
4	Haanja manor	Charte von dem im Livländischen Gouvernement, Werroschen Kreise und Raugeschen Kirchspiele belegenen publiquen Gute Hahnhof	1851	1:52,000	EAA.2072.3.55b	Haanja
5	Vana-Roosa manor	Charte von den Hofsländereien des privaten Gutes Rosenhof	1886	1:9245	EAA.3724.4.1914 s 1	Pähni
6	Krabi manor	General Charte von dem im Livländischen Gouvernement, Werroschen Kreise, Raugeschen Kirchspiele belegenen privaten Gute Schönangern	1887	1:52,000	EAA.2469.1.769	Paganamaa
7	Map of six farms	Charte des zu dem Privatgute Rosenhof gehörigen Grundstücks Waldeshöh oder die Gesinden Alska, Orrando, Surepeter Jaan, Gusta, Adam und die Buschw. Jaenesse	1876	Not presented	EAA.2072.5.643 s 1	Paganamaa
8	Farm map	Charte des zu dem Privatgute Rosenhof gehörigen Gesindes Wastne Sockari Nr.37	1874	1:52,000	EAA.2486.3.276 s 63	Paganamaa
9	Farm map	Charte des zu dem Privatgute Rosenhof gehörigen Gesindes Tagga Kerrekutzi Nr.39	1874	1:52,000	EAA.2486.3.276 s 39	Paganamaa

Appendix B

List of vascular plant species with abbreviations (only for species used in multivariate analyses). The coverage data involve ground vegetation and the proportion of stands with species presence, average coverages by land use groups (RB – recent *buschlands*, OB – older *buschlands*, CF – continuous forests) and p-values (permutation analysis of variance) are presented. The presence data involve ground-layer vascular plants, bushes and trees, and the proportion of stands with species presence, average presence by land use groups and p-values (Fisher exact test) are presented. Species with statistically significant differences between groups ($p < 0.05$) either in coverage or presence are presented in bold face. Finally, the ancient forest indicators (AFI) by Wulff (0 – no, 1 – yes), the dispersal types and affinities for human impact (hf – hemeraphobes, hd – hemeradiaphores, ap – apophytes, an – antropophytes) are denoted.

Species	Abbreviation	Coverage,%					Presence					AFI by Wulff	Disp. types	Affinities to human impact
		Prop. of stands	RB	OB	CF	p-Value	Prop. of stands	RB	OB	CF	p-Value			
Acer platanoides	Acer plat	67.5%	0.550	0.182	0.221	0.053	75.9%	0.872	0.640	0.545	**0.015**	0	ane	hd
Actaea spicata	Acte spic	33.7%	0.156	0.055	0.120	0.418	33.7%	0.404	0.182	0.280	0.327	0	end	hf
Aegopodium podagraria	Aego pod	15.7%	0.047	0.055	0.128	0.493	15.7%	0.106	0.273	0.200	0.242	0	bar, loom	ap
Alnus incana		4.8%	0.017	0.000	0.000	0.270	22.9%	0.319	0.273	0.040	**0.015**	0	hyd	ap
Amelanchier spicata		3.6%	0.021	0.000	0.000	0.478	12.0%	0.149	0.182	0.040	0.315	0	end	an
Anemone nemorosa	Anem nemo	31.3%	0.251	0.036	0.253	0.581	31.3%	0.277	0.091	0.480	0.057	0	myr, end	hd
Angelica sylvestris	Ange sylv	4.8%	0.015	0.000	0.013	0.917	4.8%	0.043	0.000	0.080	0.779	0	ane	hd
Anthriscus sylvestris	Anth sylv	28.9%	0.140	0.073	0.069	0.355	28.9%	0.319	0.273	0.240	0.837	0	aut	ap
Asarum europaeum	Asar euro	6.0%	0.043	0.000	0.024	0.842	6.0%	0.064	0.000	0.080	1.000	0	myr	hf
Athyrium filix-femina	Athy fili	13.3%	0.030	0.055	0.173	0.087	13.3%	0.064	0.182	0.240	0.091	0	ane	hd
Betula pendula	Betu pend	25.3%	0.070	0.036	0.056	0.696	81.9%	0.894	0.818	0.680	0.083	0	ane	ap
Calamagrostis arundinacea	Cala arun	47.0%	0.331	0.230	0.584	0.322	47.0%	0.298	0.636	0.720	**0.001**	0	un	ap
Calamagrostis epigeios		2.4%	0.000	0.055	0.000	**0.019**	2.4%	0.000	0.182	0.000	**0.016**	0	end	hd
Calluna vulgaris		2.4%	0.000	0.018	0.008	0.173	2.4%	0.000	0.091	0.040	0.097	0	ane	hd
Campanula glomerata		1.2%	0.000	0.018	0.000	0.127	1.2%	0.000	0.091	0.000	0.133	0	bar	ap
Campanula persicifolia	Camp pers	10.8%	0.014	0.036	0.037	0.386	10.8%	0.064	0.182	0.160	0.264	0	bar	hd
Carex canescens		4.8%	0.000	0.000	0.032	**0.013**	4.8%	0.000	0.000	0.160	**0.014**	0	un	ap
Carex leporina		1.2%	0.009	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	un	ap
Carex rhizina		1.2%	0.000	0.000	0.008	0.428	1.2%	0.000	0.000	0.040	0.434	0	un	hf
Carex sylvatica		4.8%	0.004	0.000	0.032	0.110	4.8%	0.021	0.000	0.120	0.163	1	myr	hf
Carex vaginata		2.4%	0.000	0.000	0.016	0.114	2.4%	0.000	0.000	0.080	0.185	0	un	hd
Carex brunnescens		3.6%	0.000	0.000	0.040	**0.041**	3.6%	0.000	0.000	0.120	**0.042**	0	un	hf
Carex ericetorum		1.2%	0.004	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	un	ap
Carex nigra		1.2%	0.004	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	un	ap
Carex spicata		1.2%	0.005	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	un	ap
Carex digitata	Care digi	56.6%	0.430	0.364	0.399	0.920	56.6%	0.532	0.636	0.600	0.778	0	myr	hd
Chelidonium majus	Chel maju	8.4%	0.024	0.618	0.000	**0.010**	8.4%	0.085	0.273	0.000	**0.027**	0	myr, end	an
Chimaphila umbellata		2.4%	0.000	0.030	0.008	0.059	2.4%	0.000	0.091	0.040	0.097	0	auto, ane	hf
Circaea alpina	Circ alpi	8.4%	0.023	0.121	0.015	**0.039**	8.4%	0.064	0.273	0.040	0.093	1	bar	hf
Cirsium oleraceum		1.2%	0.000	0.000	0.008	0.435	1.2%	0.000	0.000	0.040	0.434	0	ane	hd
Cirsium palustre		3.6%	0.004	0.048	0.000	**0.027**	3.6%	0.021	0.182	0.000	0.070	0	ane	ap
Cirsium.heterophyllum		1.2%	0.000	0.018	0.000	0.140	1.2%	0.000	0.091	0.000	0.133	0	ane	ap
Convallaria majalis	Conv maja	33.7%	0.207	2.036	1.371	**0.034**	33.7%	0.191	0.364	0.600	**0.002**	0	end	hd
Corylus avellana	Cory avel	49.4%	0.248	0.127	0.176	0.304	65.1%	0.745	0.455	0.560	0.088	0	end	hd
Crepis paludosa	Crep palu	12.0%	0.009	0.036	0.136	**0.015**	12.0%	0.043	0.182	0.240	**0.029**	0	ane	hd
Dactylis glomerata	Dact glom	8.4%	0.026	0.036	0.008	0.671	8.4%	0.085	0.182	0.040	0.319	0	niit	ap
Daphne mezereum		0.0%					6.0%	0.000	0.091	0.160	**0.014**	0	en	hd

Deschampsia cespitosa	Decs caes	22.9%	0.061	0.018	0.082	0.434	22.9%	0.234	0.091	0.280	0.538	0	un	ap
Dryopteris carthusiana	Dryo char	97.6%	1.193	1.127	2.118	0.099	97.6%	1.000	0.909	0.960	0.097	0	ane	hd
Dryopteris carthusiana X expansa	Dryo eXch	6.0%	0.047	0.055	0.208	0.447	6.0%	0.021	0.182	0.080	0.074	0	ane	hd
Dryopteris expansa	Dryo expa	7.2%	0.004	0.000	0.528	**0.020**	7.2%	0.021	0.000	0.200	**0.020**	0	ane	hf
Dryopteris filix-mas	Dryo fili	28.9%	0.191	0.400	0.603	0.288	28.9%	0.319	0.091	0.320	0.338	0	ane	hd
Elymus caninus		1.2%	0.000	0.000	0.008	0.440	1.2%	0.000	0.000	0.040	0.434	0	epi	hd
Epilobium angustifolium	Epil angu	21.7%	0.047	0.121	0.056	0.214	21.7%	0.149	0.455	0.240	0.070	0	ane	ap
Epilobium montanum	Epil mont	26.5%	0.082	0.018	0.058	0.261	26.5%	0.298	0.091	0.280	0.439	0	ane	ap
Equisetum hyemale		3.6%	0.017	0.018	0.000	0.688	3.6%	0.043	0.091	0.000	0.235	1	ane	hd
Equisetum pratense	Equi prat	45.8%	0.313	0.236	0.224	0.559	45.8%	0.553	0.455	0.280	0.086	0	ane	hd
Equisetum sylvaticum	Equi sylv	15.7%	0.028	0.018	0.120	**0.049**	15.7%	0.106	0.091	0.280	0.157	1	ane	hd
Festuca ovina	Fest ovin	44.6%	0.139	0.309	0.241	0.129	44.6%	0.404	0.455	0.520	0.671	0	un	ap
Festuca rubra	Fest rubr	8.4%	0.014	0.055	0.016	0.220	8.4%	0.064	0.182	0.080	0.384	0	un	ap
Filipendula ulmaria		1.2%	0.004	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	bar, hyd	ap
Fragaria vesca	Frag vesc	85.5%	0.991	0.848	0.703	0.503	85.5%	0.936	0.818	0.720	**0.031**	0	endo	ap
Frangula alnus	Fran alnu	73.5%	0.365	0.315	0.330	0.854	95.2%	0.979	0.909	0.920	0.247	0	endo	hd
Fraxinus exelsior	Frax exel	7.2%	0.045	0.000	0.000	0.134	19.3%	0.298	0.091	0.040	**0.017**	0	ane	hd
Galeobdolon luteum	Gale lute	38.6%	1.555	1.455	4.029	0.102	38.6%	0.383	0.273	0.440	0.660	1	myr	hd
Galeopsis tetrahit	Gale tetr	26.5%	0.043	0.200	0.180	**0.006**	26.5%	0.149	0.364	0.440	**0.020**	0	epi	an
Galium album	Gali alba	15.7%	0.062	0.139	0.028	0.205	15.7%	0.170	0.273	0.080	0.299	0	epi	ap
Galium boreale		2.4%	0.000	0.055	0.000	**0.012**	2.4%	0.000	0.182	0.000	**0.016**	0	epi	ap
Galium triflorum		3.6%	0.024	0.000	0.000	0.470	3.6%	0.064	0.000	0.000	0.706	0	epi	hd
Geranium sylvaticum		1.2%	0.000	0.018	0.000	0.117	1.2%	0.000	0.091	0.000	0.133	0	aut	hd
Geum rivale	Geum riva	10.8%	0.048	0.018	0.010	0.463	10.8%	0.149	0.091	0.040	0.361	0	epi	ap
Geum urbanum	Geum urba	12.0%	0.039	0.073	0.024	0.571	12.0%	0.128	0.273	0.040	0.132	0	epi	ap
Goodyera repens	Good repe	50.6%	0.270	0.394	0.319	0.642	50.6%	0.447	0.545	0.600	0.474	0	ane	hd
Grossularia reclinata		2.4%	0.004	0.000	0.008	1.000	4.8%	0.064	0.000	0.040	1.000	0	end	ap
Gymnocarpium dryopteris	Gymn dryo	31.3%	0.144	0.127	0.346	0.168	31.3%	0.319	0.091	0.400	0.197	0	ane	hd
Helictotrichon pratense		1.2%	0.004	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	un	ap
Hepatica nobilis	Hepa nobi	18.1%	0.509	0.564	1.512	0.317	18.1%	0.128	0.273	0.240	0.362	1	myr	hd
Hieracium murorum	Hier muro	8.4%	0.017	0.055	0.096	0.360	8.4%	0.064	0.182	0.080	0.384	0	ane	un
Hieracium vulgatum	Hier vulg	15.7%	0.048	0.036	0.056	0.891	15.7%	0.170	0.091	0.160	1.000	0	ane	hd
Hieracium umbellatum		1.2%	0.013	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	ane	ap
Huperzia selago	Hupe sela	6.0%	0.010	0.000	0.032	0.286	6.0%	0.043	0.000	0.120	0.402	0	ane	hd
Hypochaeris maculata		1.2%	0.000	0.000	0.024	0.409	1.2%	0.000	0.000	0.040	0.434	0	ane	hd
Impatiens parviflora	Imp parv	33.7%	0.480	0.073	0.360	0.435	33.7%	0.383	0.091	0.360	0.187	0	aut	an
Juniperus communis		0.0%	–	–	–	–	8.4%	0.085	0.182	0.040	0.319	0	end	ap
Knautia arvensis		1.2%	0.000	0.018	0.000	0.147	1.2%	0.000	0.091	0.000	0.133	0	epi, myr	ap
Lathyrus vernus		1.2%	0.000	0.036	0.000	0.143	1.2%	0.000	0.091	0.000	0.133	0	aut, end, epi	hf
Lonicera xylosteum	Loni xylo	21.7%	0.072	0.018	0.208	0.089	30.1%	0.298	0.091	0.400	0.190	0	end	hd
Luzula pilosa	Luzu pilo	100.0%	0.835	0.836	0.836	1.000	100.0%	1.000	1.000	1.000	1.000	0	myr	hd
Lycodium annotinum	Lyco anno	30.1%	0.060	0.091	0.365	0.117	30.1%	0.234	0.455	0.360	0.255	0	ane	hd
Lycopodium clavatum	Lyco clav	14.5%	0.021	0.091	0.029	0.066	14.5%	0.106	0.273	0.160	0.339	0	ane	hd

Lysimachia vulgaris	Lysi vulg	10.8%	0.009	0.018	0.085	0.055	10.8%	0.043	0.091	0.240	**0.037**	0	bar, end	ap
Maianthemum bifolium	Maia bifo	95.2%	2.151	1.909	2.100	0.946	95.2%	0.936	1.000	0.960	1.000	0	end	hd
Malus domestica		2.4%	0.004	0.000	0.008	1.000	7.2%	0.043	0.091	0.120	0.386	0	end	an
Melampyrum nemorosum	Mela nemo	6.0%	0.000	0.018	0.055	**0.029**	6.0%	0.000	0.091	0.160	**0.014**	0	myr	hd
Melampyrum pratense	Mela prat	32.5%	0.071	0.158	0.271	**0.017**	32.5%	0.234	0.364	0.480	0.104	0	myr	hd
Melampyrum sylvaticum	Mela sylv	48.2%	0.231	0.176	0.197	0.822	48.2%	0.489	0.455	0.480	1.000	0	myr	hd
Melica nutans	Meli nuta	30.1%	0.146	0.273	0.080	0.096	30.1%	0.319	0.364	0.240	0.707	0	myr	hd
Mentha arvensis		1.2%	0.000	0.018	0.000	0.149	1.2%	0.000	0.091	0.000	0.133	0	myr, epi	ap
Milium effusum		2.4%	0.000	0.000	0.024	0.227	2.4%	0.000	0.000	0.080	0.185	0	ane	hd
Moehringia trinervia	Moeh trin	41.0%	0.160	0.309	0.162	0.295	41.0%	0.426	0.455	0.360	0.815	0	myr	hd
Moneses uniflora		4.8%	0.007	0.036	0.024	0.471	4.8%	0.021	0.182	0.040	0.104	0	auto, ane	hf
Mycelis muralis	Myce mura	94.0%	0.713	0.552	0.576	0.195	94.0%	0.957	0.909	0.920	0.525	0	ane	hd
Orthilia secunda	Orth secu	39.8%	0.174	0.164	0.169	0.997	39.8%	0.426	0.364	0.360	0.858	0	auto, ane	hf
Oxalis acetosella	Oxal acet	98.8%	19.992	17.570	20.696	0.700	98.8%	1.000	1.000	0.960	0.434	0	aut, myr	hd
Paris guadrifolia	Pari guad	43.4%	0.304	0.121	0.180	0.401	43.4%	0.489	0.364	0.360	0.496	1	end	hf
Phegopteris connectilis		3.6%	0.004	0.000	0.048	0.273	3.6%	0.021	0.000	0.080	0.529	0	ane	hd
Phyteuma spicatum		1.2%	0.000	0.018	0.000	0.151	1.2%	0.000	0.091	0.000	0.133	1	ane	hf
Picea abies	Pice abie	73.5%	0.323	0.267	0.418	0.259	100.0%	1.000	1.000	1.000	1.000	0	ane	hd
Pinus sylvesteris		2.4%	0.004	0.018	0.000	0.357	92.8%	0.957	1.000	0.840	0.163	0	ane	hd
Poa angustifolia		1.2%	0.004	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	un	hd
Poa nemoralis	Poa nemo	18.1%	0.047	0.055	0.048	1.000	18.1%	0.170	0.273	0.160	0.722	0	ane	hd
Poa pratensis		2.4%	0.000	0.036	0.000	**0.022**	2.4%	0.000	0.182	0.000	**0.016**	0	un	ap
Poa trivialis		1.2%	0.000	0.018	0.000	0.126	1.2%	0.000	0.091	0.000	0.133	0	un	ap
Polygonatum odoratum	Poly odor	10.8%	0.009	0.073	0.122	**0.045**	10.8%	0.043	0.091	0.240	**0.037**	0	end	hd
Populus tremula	Popu trem	34.9%	0.198	0.091	0.040	**0.013**	50.6%	0.702	0.182	0.280	**0.000**	0	un	ap
Potentilla erecta	Pote erec	2.4%	0.000	0.036	0.000	**0.016**	2.4%	0.000	0.182	0.000	**0.016**	0	loom	ap
Padus avium	Padu aviu	8.4%	0.057	0.036	0.000	0.197	16.9%	0.277	0.091	0.000	**0.004**	0	end	hd
Prunella vulgaris		2.4%	0.004	0.000	0.008	1.000	2.4%	0.021	0.000	0.040	1.000	0	epi	ap
Pteridium aquilinum	Pter aqui	75.9%	1.141	3.285	1.949	0.164	75.9%	0.809	0.727	0.680	0.448	0	ane	ap
Pyrorola chlorantha		1.2%	0.004	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	auto, ane	hf
Pyrola rotundifolia	Pyro rotu	10.8%	0.031	0.091	0.024	0.330	10.8%	0.106	0.091	0.120	1.000	0	auto, ane	hd
Pyrola minor		1.2%	0.000	0.000	0.016	0.440	1.2%	0.000	0.000	0.040	0.434	0	auto, ane	hf
Quercus robur	Quer robu	74.7%	0.429	0.327	0.287	0.149	85.5%	0.957	0.909	0.640	**0.001**	0	epi	hd
Ranunculus acris		4.8%	0.010	0.000	0.016	0.605	4.8%	0.043	0.000	0.080	0.779	0	epi	ap
Ranunculus cassubicus		1.2%	0.000	0.018	0.000	0.126	1.2%	0.000	0.091	0.000	0.133	0	epi	hd
Rhamnus catharticus		2.4%	0.009	0.000	0.000	0.664	4.8%	0.085	0.000	0.000	0.441	0	end	hd
Ribes alpinum	Ribe alpi	21.7%	0.069	0.036	0.160	0.230	27.7%	0.234	0.273	0.360	0.507	0	end	hd
Ribes nigrum		2.4%	0.009	0.000	0.000	0.676	4.8%	0.085	0.000	0.000	0.441	0	end	hd
Ribes spicatum	Ribe spic	6.0%	0.021	0.000	0.000	0.152	22.9%	0.319	0.182	0.080	0.062	0	end	hd
Rosa subcanina		0.0%	–	–	–	–	1.2%	0.021	0.000	0.000	1.000	0	end	ap
Rubus saxatilis	Rubs saxa	91.6%	4.831	4.055	4.484	0.819	91.6%	0.936	0.909	0.880	0.646	0	end	hd
Rubus idaeus	Rubu idae	86.7%	1.777	1.442	1.178	0.460	86.7%	0.872	0.818	0.880	0.809	0	end	ap

Rubus nessensis		2.4%	0.004	0.000	0.008	1.000	2.4%	0.021	0.000	0.040	1.000	0	end	ap
Rumex acetosella		1.2%	0.000	0.000	0.008	0.425	1.2%	0.000	0.000	0.040	0.434	0	bar end	ap
Salix caprea		1.2%	0.000	0.000	0.008	0.440	8.4%	0.021	0.182	0.160	**0.035**	0	ane	ap
Sambucus racemosa	Samb race	21.7%	0.099	0.073	0.069	0.868	30.1%	0.340	0.273	0.240	0.707	0	ane	ap
Sanicula euroaea		1.2%	0.000	0.000	0.008	0.440	1.2%	0.000	0.000	0.040	0.434	1	epi	hf
Scorzonera humilis		2.4%	0.005	0.000	0.008	1.000	2.4%	0.021	0.000	0.040	1.000	0	ane	ap
Scrophularia nodosa		2.4%	0.004	0.000	0.008	1.000	2.4%	0.021	0.000	0.040	1.000	0	ane	ap
Solidago virgaurea	Soli virg	85.5%	0.480	0.576	0.479	0.668	85.5%	0.830	0.909	0.880	0.910	0	ane	ap
Sorbus aucuparia	Sorb aucu	97.6%	0.784	0.564	0.659	**0.050**	98.8%	1.000	1.000	0.960	0.434	0	end	ap
Stachys sylvatica		1.2%	0.013	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	1	epi	hd
Stellaria holostea		3.6%	0.000	0.018	0.072	0.067	3.6%	0.000	0.091	0.080	0.106	0	bar	hf
Stellaria longifolia	Stel long	7.2%	0.010	0.036	0.024	0.455	7.2%	0.043	0.091	0.120	0.386	0	endo, epi	hf
Stellaria nemorum	Stel nemo	19.3%	0.064	0.455	0.256	0.104	19.3%	0.170	0.273	0.200	0.681	0	hyd	hd
Taracaxu sp.	Tara sp	13.3%	0.042	0.036	0.024	0.793	13.3%	0.149	0.091	0.120	1.000	0	ane	un
Trientalis europaea	Trie euro	90.4%	0.717	0.800	0.699	0.723	90.4%	0.894	1.000	0.880	0.757	0	bar, ane	hd
Trifolium medium		1.2%	0.000	0.018	0.000	0.135	1.2%	0.000	0.091	0.000	0.133	0	aut, end, epi	ap
Tussilago farfara		1.2%	0.004	0.000	0.000	1.000	1.2%	0.021	0.000	0.000	1.000	0	ane	ap
Ulmus glabra		0.0%	–	–	–	–	3.6%	0.043	0.000	0.040	1.000	0	ane, end	hd
Urtica dioica	Urti dioi	32.5%	0.126	0.218	0.087	0.248	32.5%	0.319	0.455	0.280	0.608	0	bar, zoo	ap
Vaccinium myrtillus	Vacc myrt	98.8%	9.567	7.018	8.620	0.485	98.8%	0.979	1.000	1.000	1.000	0	end	hd
Vaccinium vitis-ideaea	Vacc viti	77.1%	0.581	2.194	0.739	**0.005**	77.1%	0.787	0.727	0.760	0.814	0	end	hd
Veronica chamaedrys	Vero chae	21.7%	0.052	0.091	0.060	0.641	21.7%	0.213	0.273	0.200	0.864	0	myr, bar	ap
Veronica officinalis	Vero offi	48.2%	0.171	0.236	0.116	0.240	48.2%	0.532	0.455	0.400	0.610	0	myr, bar	ap
Viburnum opulus	Vibu opul	36.1%	0.169	0.091	0.120	0.549	37.3%	0.447	0.273	0.280	0.293	0	endo	hd
Vicia sepium		1.2%	0.000	0.036	0.000	0.150	1.2%	0.000	0.091	0.000	0.133	0	auto	ap
Viola canina		1.2%	0.000	0.000	0.008	0.420	1.2%	0.000	0.000	0.040	0.434	0	auto, myr, end	hd
Viola palustris	Viol palu	10.8%	0.021	0.018	0.120	0.211	10.8%	0.085	0.091	0.160	0.697	0	auto, myr, end	hd
Viola riviniana	Viol rivi	60.2%	0.361	0.345	0.212	0.174	60.2%	0.617	0.727	0.520	0.484	0	auto, myr, end	hd

Appendix C

List of bryophyte species, their average presence by past land use groups and p-values (Fisher exact test); species with statistically significant difference between groups (p < .05) are presented in bold face.

Species	Mean			P-value
	Recent buschlands	Old buschlands	Continuous forests	
Atrichum undulatum	0.048	0.000	0.082	0.149
Brachythecium oedipodium	**0.427**	**0.285**	**0.197**	**0.002**
Brachythecium reflexum	0.035	0.000	0.048	0.467
Brachythecium rutabulum	0.007	0.000	0.008	1.000
Brachythecium salebrosum	0.014	0.000	0.000	0.672
Brachythecium starkei	0.004	0.000	0.000	1.000
Brachythecium velutinum	0.026	0.000	0.016	0.673
Cephalozia bicuspidata	0.004	0.000	0.000	1.000
Cirriphyllum piliferum	0.068	0.036	0.144	0.131
Climacium dendroides	0.005	0.000	0.008	1.000
Dicranum majus	0.050	0.036	0.040	0.932
Dicranum montanum	0.000	0.000	0.016	0.415
Dicranum polysetum	0.157	0.145	0.255	0.183
Dicranum scoparium	0.288	0.424	0.316	0.355
Eurhynchium angustirete	**0.287**	**0.055**	**0.181**	**0.033**
Eurhynchum hians	0.026	0.000	0.000	0.455
Eurhynchium pulchellum	0.009	0.000	0.000	0.637
Eurhynchum stratum	0.074	0.018	0.008	0.218
Herzogiella seligeri	0.004	0.018	0.008	0.680
Hylocomium splendens	0.821	0.855	0.864	0.790
Hylocomium umbratum	0.000	0.018	0.008	0.195
Hypnum cupressiforme	0.013	0.000	0.000	0.264
Hypnum pallescens	0.004	0.000	0.000	1.000
Lophocolea bidentata	0.000	0.000	0.008	0.443
Lophocolea heterophylla	0.033	0.067	0.032	0.619
Lophocolea minor	0.004	0.000	0.000	1.000
Plagiochila asplenioides	**0.116**	**0.164**	**0.284**	**0.015**
Plagiothecium curvifolium	0.004	0.000	0.008	1.000
Plagiothecium denticulatum	0.000	0.018	0.000	0.136
Plagiothecium latebricola	0.004	0.000	0.000	1.000
Plagiochila porelloides	0.004	0.000	0.008	1.000
Plagiomnium affine	**0.689**	**0.521**	**0.468**	**0.011**
Plagiomnium cuspidatum	0.039	0.000	0.000	0.071
Plagomnium elatum	0.009	0.000	0.032	0.319
Plagiomnium ellipticum	0.036	0.000	0.016	0.406
Plagiomnium undulatum	0.009	0.000	0.008	1.000
Plagiothecium curvifolium	0.021	0.018	0.032	0.874
Pleurozium schreberi	0.694	0.764	0.686	0.796
Pohlia nutans	0.004	0.000	0.000	1.000
Polytrichum commune	0.009	0.000	0.032	0.328
Polytrichum formosum	**0.021**	**0.085**	**0.096**	**0.049**
Polytrichum juniperinum	0.010	0.000	0.000	0.672
Ptilium crista-castrensis	0.093	0.158	0.128	0.620
Ptilidium pulcherrimum	0.004	0.018	0.000	0.328
Rhodobryum roseum	0.140	0.218	0.166	0.541
Rhytidiadelphus subpinnatus	0.000	0.018	0.040	0.250
Rhytidiadelphus triquetrus	**0.463**	**0.218**	**0.294**	**0.022**
Sanionia uncinata	0.025	0.000	0.024	0.693
Sphagnum angustifoilum	0.004	0.000	0.000	1.000
Sphagnum girgensohnii	0.013	0.018	0.008	1.000
Sphagnum sp.	0.009	0.000	0.000	1.000

Appendix D

List of measured and deduced environmental variables and soil properties with short description, abbreviations (if used in figures or tables in text), range of values, average values by past land use groups and p-values (permutation analysis of variance; variables with statistically significant difference between groups are presented in bold face).

Variable.name	Abbreviation	Range of values	Mean			P-value
			Recent *buschlands*	Old *buschlands*	Continuous forests	
Human impacts						
Past land use patch: (1) recent buschland < (2) older buschland < (3) continuous forest	Group	1–3	–	–	–	–
Land cover 1912–1922: (1) open < (2) transitional < (3) forest	Development	1–3	2.21	2.73	2.93	**< 0.001**
Human impact: summed index of estimations of various human impacts from 20–21 century	Human impact	0–9	2.74	2.20	2.48	0.617
Large relict trees: (0) missing, (1) single or few, (2) medium, (3) numerous	Large trees	0–3	1.152	0.618	0.144	**< 0.001**
Field banks: (0) missing, (1) single, (2) few (3) numerous	Field banks	0–3	1.105	1.139	0.000	**< 0.001**
Turnip pits: (0) missing, (1) present, (2) well maintained (3) numerous	Turnip pits	0–3	0.301	0.176	0.016	**0.035**
Landscape characteristics						
Location of the sites in landscape: (1) isolated < (2) edge < (3) massive	Location	1–3	2.481	2.909	2.904	**0.001**
Situation in the landscape expressed as (1) flat land < (2) the tops of hills < (3) the base of hills < (4) hill slopes	Relief	1–4	2.635	2.764	2.220	0.174
Average area of forest stand by FMDs (ha)	Area	0.4–15.2	2.094	1.827	3.916	**0.005**
Tree cover						
Average age of dominant tree species by FMD	Age	94–178	112.7	133.1	130.3	**< 0.001**
Average basal area of *Betula pendula* (cm^2)		0.0–2192.7	289.1	380.6	368.2	0.707
Average basal area of *Alnus incana* (cm^2)	Alnus	0.0–152.1	4.83	15.63	0.06	0.111
Average basal area of *Corylus avellana* in sample plot (cm^2)	Corylus	0.0–3152.4	177.5	268.3	244.2	0.807
Average basal area of *Picea abies* in sample plot (cm^2)	Picea	0.0–4335.9	2143.7	2306.9	2274.0	0.789
Average basal area of *Pinus sylvestris* in sample plot (cm^2)	Pinus	0.0–5750.5	1934.5	2132.1	1896.7	0.897
Average basal area of all trees in sample plot (cm^2)	Basal	1.6–8951.4	4962.0	5290.8	4696.1	0.415
Average basal area of trees with diameter 5 cm or less in sample plot (cm^2)		0.0–3225.9	274.8	259.4	248.2	0.973
Average basal area of *Picea abies* with diameter ≤ 5 cm (height more than 1.3 m) in sample plot (cm^2)	sPicea	0.0–1975.5	76.9	31.5	54.4	0.884
Estimated amount of regeneration of *Picea abies* in sample plot	regPicea	0.0–2.0	0.565	0.752	0.740	0.524
Forest elements						
Average basal area of dead standing trees in sample plot (cm^2)	DWstanding	0.0–4790.5	265.2	246.4	417.3	0.493
Average number of fallen dead tree trunks with diameter ≥ 10 recorded on the ground in the plot	DWlaying	0.8–7.8	2.89	3.27	3.11	0.682
Average number of tree stumps in the sample plot	Stumps	0.0–3.0	0.995	0.818	0.975	0.693
Average number of cut tree stumps in the sample plot		0.0–3.0	0.449	0.455	0.455	0.811
Average number of natural tree stumps in the sample plot		0.0–3.0	0.546	0.364	0.551	0.689
Average number of uprooted trees in sample plot	Uproots	0.0–1.0	0.226	0.230	0.242	0.968
Estimated damages of wild boars to the ground vegetation in sample plot	Boar	0.0–2.4	0.638	0.527	0.608	0.792
Soil characteristics						
Litter thickness (cm)	**Litter**	**1.0–12.0**	**4.79**	**6.55**	**6.12**	**0.016**
Humus layer thickness (cm)	Humus	0.0–35.0	15.06	12.09	12.56	0.077
Soil texture: (1) coarse sand < (2) fine sand < (3) sandy loam < (4) light loam < (5) medium loam	Texture	0.0–2.9	2.21	2.18	1.92	0.465
Soil type: (1) Podzols and Gleyic soils < (2) Haplic Albeluvisols and Delluvial soils < (3) Stagnic Luvisols < (4) Mollic Cambisols and Luvisols	Soil	1–4	2.32	2.06	2.52	0.409
pHKCl of humus layer	pHKCl	2.7–6.8	3.74	3.77	3.74	0.979
Nitorgen in humus layer (%)	N	0.01–1.47	0.275	0.188	0.352	0.434
Carbon in humus layer (%)	C	0.05–6.20	1.223	1.207	0.833	0.456
pHKCl under humus layer		3.3–6.9	4.12	4.30	4.33	0.221

Nitorgen under humus layer (%)		0.00–0.75	0.085	0.071	0.053	0.733
Carbon under humus layer (%)		0.02–1.78	0.384	0.402	0.311	0.733
Soil specific surface area of humus layer (g/m^2)		3.6–83.8	24.5	25.9	21.2	0.564
Soil specific surface area under humus layer (g/m^2)		3.3–57.9	16.1	16.6	16.5	0.955
C/N ratio in humus layer	CN ratio	0.1–108.9	11.4	14.2	18.6	0.176
Mollic Cambisols and Luvisols		0.2–1.0	0.081	0.109	0.016	0.377
Stagnic Luvisols		0.2–1.0	0.330	0.127	0.256	0.346
Haplic albeluvisols		0.4–1.0	0.421	0.545	0.624	0.239
Podzols		0.2–1.0	0.068	0.091	0.080	1.000
Delluvial soils		0.2–1.0	0.079	0.073	0.024	0.492
Gleyic soils		0.6–1.0	0.021	0.055	0.000	0.664

References

Aavik, T., Püssa, K., Roosaluste, E., Moora, M., 2009. Vegetation change in boreonemoral forest during succession – trends in species composition, richness and differentiation diversity. Ann. Bot. Fenn. 46, 326–335. http://dx.doi.org/10.5735/085.046.0408.

Asi, E., Kõlli, R., Laas, E. (Eds.), 2004. E. Afforestation of Arable Land. Guidelines for afforestation of arable land. Metsakaitse- ja Metsauuenduskeskus, Tartu, 83 pp. (in Estonian).

Astover, A., Kõlli, R., Roostalu, H., Reintam, E., Leedu, E., 2012. Soil science. Texbook for Highschools. Eesti Maaülikool, Tartu, 486 pp. (in Estonian).

Axelsson, A.L., Östlund, L., 2001. Retrospective cap analyses in Swedish boreal forest landscape using historical data. For. Ecol. Manage. 147 (2–3), 109–122. http://dx.doi.org/10.1016/S0378-1127(00)00470-9.

Bigham, J.M. (Ed.), 1996. Methods of Soil Analysis. Part 3. Chemical Analysis. Number 5 in the Soil Science Society of America Book Series. Soil Science Society of America, Inc., Madisson, Wisconsin, USA, pp. 1390.

BioClim, 2015. The analyse of impacts of climate changes, adaption strategy and action plan. Natural environment (I) and bio-economy (II). < http://www.klab.ee/kohanemine/wp-content/uploads/sites/4/2016/04/2016-04-07-BIOCLIM_Lopparuanne.pdf > .

Bolte, A., Hilbrig, L., Grundmann, B., Kampf, F., Brunet, J., Roloff, A., 2010. Climate change impacts on stand structure and competitive interactions in a southern Swedish spruce–beech forest. Eur. J. Forest. Res. 129, 261–276. http://dx.doi.org/10.1007/s10342-009-0323-1.

Bonan, G.B., Shugart, H.H., 1989. Environmental factors and ecological processes in boreal forests. Annu. Rev. Ecol. Syst. 20, 1–28. http://dx.doi.org/10.1146/annurev.ecolsys.20.1.1.

Bradshaw, R., Hannon, G., 1992. Climatic change, human influence and disturbance regime in the control of vegetation dynamics within Fiby Forest, Sweden. J. Ecol. 80 (4), 625–632. http://dx.doi.org/10.2307/2260854.

Brūmelis, G., Jonsson, B.G., Kouki, J., Kuuluvainen, T., Shorohova, E., 2011. Forest naturalness in Northern Europe: perspectives on processes, structures and species diversity. Silva Fenn. 45 (5), 807–821. http://dx.doi.org/10.14214/sf.446.

Bunce, R.G.H., Shaw, M.W., 1973. A standardised method for ecological survey. J. Environ. Manage. 1, 239–258.

Cowling, S.A., Sykes, M.T., Bradshaw, R.H.W., 2001. Paleovegetation-model comparisons, climate change and tree succession in Scandinavia over the past 1500 years. In: J. Ecol. 89. pp. 227–236 10.1.1.528.9889.

Delgado-Matas, C., 2004. Dynamics of nutrients in slash and burn agroforestry in Koli National Park. In: In: Lovén, L. (Ed.), Tutkittu ja tuntematon Koli, vol. 915. Metsäntutkimuslaitoksen tiedonantoja, pp. 29–46.

Dupouey, J.L., Dambrine, E., Laffite, J.D., Moares, C., 2002. Irreversible impact of past land use on forest soils and biodiversity. Ecology 83 (11), 2978–2984. http://dx.doi.org/10.2307/3071833.

Environment Agency, 2017. Public Service for the State Forest Management Database (FMD). < http://register.metsad.ee/avalik/ > .

Eriksson, S., Skånes, H., Hammer, M., Lönn, M., 2010. Current distribution of older and deciduous forests as legacies from historical use patterns in a Swedish boreal landscape (1725–2007). For. Ecol. Manage. 260 (7), 1095–1103. http://dx.doi.org/10.1016/j.foreco.2010.06.018.

Ericsson, T.S., Berglund, H., Östlund, L., 2005. History and forest biodiversity of woodland key habitats in south boreal Sweden. Biol. Conserv. 122, 289–303. http://dx.doi.org/10.1016/j.biocon.2004.07.019.

Estonian Land Board, 2017a. Estonian Soil Map. < http://xgis.maaamet.ee/xGIS/XGis?app_id=UU38&user_id=at&bbox=656053.598921743,6397890.11467557,660895.401900824,6400381.04224126&LANG=1 > .

Estonian Land Board, 2017b. Web Map Server Historical Map Application. < http://xgis.maaamet.ee/xGIS/XGis?app_id=UU41&user_id=at&bbox=174004.405286344,6315000,915995.594713656,6663000&LANG=1 > (accessed 06.03.2017).

Etverk, I., 1974. They learn about the forest and management. In: Valk, U., Eilart, J. (Eds.), Estonian Forests. Valgus, Tallinn, pp. 40–60 (in Estonian).

Flinn, K.M., Vellend, M., 2005. Recovery of forest plant communities in post-agricultural landscapes front. Ecol. Environ. 3 (5), 243–250. http://dx.doi.org/10.2307/3868486.

Goldhammer, J.F., Bruce, M., 2004. The use of prescribed fire in the land management of Western and Baltic Europe: an overview. Int. For. Fire News 30, 2–13 (accessed 07.03.17).

Hamilton, H., 1997. Slash and burn in the history of Swedish forests. Rural Dev. For. Netw. Pap. 21f, 19–24. < https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/1162.pdf > (accessed 07.03.17).

Heikinheimo, O., 1915. The impacts of slash and burn cultivation in the Finnish Forests. Metsähallituksen julkaisuja II. Keisarillisen senatiin kirjapainossa, Helsinki, 264 pp. (in Finnish).

Hekkala, A.-M., Tarvainen, O., Tolvanen, A., 2014. Dynamics of understory vegetation after restoration of natural characteristics in the boreal forests in Finland. For. Ecol. Manage. 330, 55–66. http://dx.doi.org/10.1016/j.foreco.2014.07.001.

Hellberg, E., Josefsson, T., Östlund, L., 2009. The transformation of a Norway spruce dominated landscape since pre-industrial times in Northern Sweden: the influence of modern forest management on forest structure. Silva Fenn. 43 (5), 783–797. http://www.metla.fi/silvafennica/full/sf43/sf435783.pdf.

Hermy, M., Honnay, O., Firbank, L., Grashof-Bokdam, C., Lawesson, J.E., 1999. An ecological comparison between ancient and other forest plant species of Europe and the implication for forest conservation. Biol. Conserv. 91, 9–22. http://dx.doi.org/10.1016/s0006-3207(99)00045-2.

Hermy, M., Verheyen, K., 2007. Legacies of the past in the present-day forest biodiversity: a review of past land-use effects on forest plant species composition and diversity. Ecol. Res. 22, 361–371. http://dx.doi.org/10.1007/978-4-431-73238-9_1.

Hokkanen, J.P., 2006. Environmental patterns and gradients in the vascular plants and bryophytes of eastern Fennoscandian herb-rich forests. For. Ecol. Manage. 229, 73–87. http://dx.doi.org/10.1016/j.foreco.2006.03.025.

Honnay, O., Degroote, B., Hermy, M., 1998. Ancient-forest plant species in Western Belgium: a species list and possible ecological mechanism. Belg. J. Bot. 130 (2), 139–154.

Ingerpuu, N., Vellak, K. (Eds.), 1998. Keybook of Estonian Bryophytes. Eesti Loodusfoto, Tartu 239 pp (in Estonian).

Jääts, L., Kihno, K., Tomson, P., Konsa, M., 2010. Tracing fire cultivation in Estonia. For. Stud. 53, 53–65. http://dx.doi.org/10.2478/v10132-011-0089-3.

Kalamees, R., Püssa, K., Tamm, S., Zobel, K., 2012. Adaptation to boreal forest wildfire in herbs: Responses to post-fire environmental cues in two *Pulsatilla* species. Acta Oecol. 38, 1–7. http://dx.doi.org/10.1016/j.actao.2011.08.002.

Kohv, K., Liira, J., 2005. Anthropogenic effects on vegetation structure of the boreal forest in Estonia. Scand. J. For. Res. 20 (S6), 122–134. http://dx.doi.org/10.1080/14004080510041011.

Kohv, K., Zobel, M., Liira, J., 2013. The resilience of the forest field layer to anthropogenic disturbances depends on site productivity. Can. J. For. Res. 43 (11), 1040–1049. http://dx.doi.org/10.1139/cjfr-2013-0030.

Kukk, T., 1999. Vascular Plant Flora of *Estonia*. Estonian Academy of Science Press, Tartu-Tallinn 464 pp (in Estonian).

Leht, M. (Ed.), 2010. Keybook of Estonian Plants. Eesti Loodusfoto, Tartu (in Estonian).

Laasimer, L., 1958. The geobotanical characterization and development of oligotrophic sites in Estonian. In: Valk, U., Margus, M. (Eds.), The Reforestation Oligotrophic Sites and Management of Oligotrophic Forests. ZBI, Tartu, pp. 29–43 (in Estonian).

Lehtonen, H., 1998. Fire history recorded on pine trunks and stumps: Influence of land use and fires on forest structure in North Karelia. Scand. J. For. Res. 13 (1–4), 462–468. http://dx.doi.org/10.1080/02827589809383007.

Ligi, H., 1963. Agricultural land use in Estonia in XVI–XVII century, Tallinn, pp. 140 (in Estonian).

Liira, J., Sepp, T., Parrest, O., 2007. The forest structure and ecosystem quality in conditions of anthropogenic disturbance along productivity gradient. For. Ecol. Manage. 250, 34–46. http://dx.doi.org/10.1016/j.foreco.2007.03.007.

Lindbladh, M., 1999. The influence of former land-use on vegetation and biodiversity in the boreo-nemoral zone of Sweden. Ecography 22 (5), 485–498. http://dx.doi.org/10.1111/j.1600-0587.1999.tb01277.x.

Lindbladh, M., Bradshaw, R., 1998. The origin of present forest composition and pattern in Southern Sweden. J. Biogeogr. 25 (3), 463–477. http://dx.doi.org/10.1046/j.1365-2699.1998.2530463.x.

Lindbladh, M., Axelsson, A.-L., Hultberg, T., Brunet, J., Felton, A., 2014. From broadleaves to spruce – the borealization of southern Sweden. Scand. J. For. Res. 29 (7), 686–696. http://dx.doi.org/10.1080/02827581.2014.960893.

Lindner, M., Fitzgerald, J.B., Zimmermann, N.E., Reyer, C., Delzon, S., van der Maaten, E., Schelhaas, M.J., Lasch, P., Eggers, J., van der Maaten-Theunissen, M., Suckow, F., Psomas, A., Poulter, B., Hanewinkel, M., 2014. Climate change and European forests: what do we know, what are the uncertainties, and what are the implications for forest management? J. Environ. Manage. 146, 69–83. http://dx.doi.org/10.1016/j.jenvman.2014.07.030.

Linder, P., Östlund, L., 1998. Structural changes in three mid-boreal Swedish forest landscapes, 1885–1996. Biol. Conserv. 85, 9–19. http://dx.doi.org/10.1016/S0006-3207(97)00168-7.

Linkola, M., 1987. Forest as a cultural landscape. Silva Fenn. 21 (4), 362–373 (in Finnish).

Lovén, L., Äänismaa, P., 2004. Planning of the sustainable slash-and-burn cultivation programme in Koli national park, Finland. Int. For. Fire News 30, 16–21 (accessed 07.03.2017).

Lõhmus, E., 2004. Estonian Forest Site Types, second ed. Eesti Loodusfoto, Tartu (in Estonian).

Lõhmus, A., Lõhmus, P., Remm, J., Vellak, K., 2005. Old-growth structural elements in a strict reserve and commercial forest landscape in Estonia. For. Ecol. Manage. 216, 201–215. http://dx.doi.org/10.1016/j.foreco.2005.05.031.

Matuszkiewicz, J.M., Kowalska, A., Kozłowska, A., Roo-Zielińska, E., Solon, J., 2013. Differences in plant-species composition, richness and community structure in ancient and post-agricultural pine forests in central Poland. For. Ecol. Manage. 310, 567–576. http://dx.doi.org/10.1016/j.foreco.2013.08.060.

Meier, E., Paal, J., Liira, J., Jüriado, I., 2005. Influence of tree stand age and management on the species diversity in Estonian eutrophic alvar and boreo-nemoral Pinus sylvestris forests. Scand. J. of For. Res. 20 (Suppl 6), 135–144. http://dx.doi.org/10.1080/14004080510042155.

Meikar, T., Uri, V., 2000. Of the management of bushland in Estonia. In: Meikar, T., Etverk, I. (Eds.), Proceedings of the Academic Forestry Society, XI. Estonian forests and forestry at the turn of the Millennium. Tartu, pp. 103–120 (in Estonian).

Metzger, M.J., Bunce, R.G.H., Jongman, R.H.G., Mucher, C.A., Watkins, J.W., 2005. A climatic stratification of the environment of Europe. Global Ecol. Biogeogr. 14, 549–563. http://dx.doi.org/10.1111/j.1466-822X.2005.00190.x.

Moora, M., Daniell, T., Kalle, H., Liira, J., Püssa, K., Roosaluste, E., Öpik, M., Wheatley, R., Zobel, M., 2007. Spatial pattern and species richness of boreonemoral forest understorey and its determinants—a comparison of differently managed forests. For. Ecol. Manage. 250, 64–70. http://dx.doi.org/10.1016/j.foreco.2007.03.010.

Myllyntaus, T., Hares, M., Kunnas, J., 2002. Sustainability in danger? Slash-and-Burn cultivation in Nineteenth-century Finland and Twentieth-Century Southeast Asia. Environ. Hist. 7 (2), 267–302. http://dx.doi.org/10.2307/3985685.

Niinemets, E., Saarse, L., 2009. Holocene vegetation and land-use dynamics of south-eastern Estonia. Quatern. Int. 207, 104–116. http://dx.doi.org/10.1016/ j.quaint.2008.11.015.

Ohlson, M., Sörderström, L., Hörnberg, G., Zackrisson, O., Hermansson, J., 1997. Habitat qualities versus long-term continuity as determinants of biodiversity in boreal old-growth swamp forests. Biol. Conserv. 81, 221–231. http://dx.doi.org/10.1016/S0006-3207(97)00001-3.

Östlund, L., Zackrisson, O., Axelsson, A.-L., 1997. The history and transformation of a Scandinavian boreal forest landscape since the 19th century. Can J. For. Res. 27, 1198–1206. http://dx.doi.org/10.1139/cjfr-27-8-1198.

Paal, J., 1997. Classification of the Estonian vegetation site types, Tallinn, 200 pp. (in Estonian).

Paal, J., Turb, M., Köster, T., Rajandu, E., Liira, J., 2011. Forest land-use history affects the species composition and soil properties of old-aged hillock forests in Estonia. J. For. Res. 16, 244–252. http://dx.doi.org/10.1007/s10310-011-0258-5.

Parvieinen, J., 1996. Impact of fire on Finnish forest in past and today. Silva Fenn. 30 (2–3), 353–359. http://hdl.handle.net/1975/924.

Peterken, G.F., Game, M., 1984. Historical factors affecting the number and distribution of vascular plant species in the woodlands of Central Lincolnshire. J. Ecol. 72 (1), 155–182. http://dx.doi.org/10.2307/2260011.

Poska, A., Väli, V., Kama, P., Tomson, P., Vassiljev, J., Kihno, K., 2017. The postglacial history of vegetation and land use dynamics in Karula upland. In: In: Järvet, A. (Ed.), Yearbook of the Estonian Geographical Society, vol. 42. Vali Press OÜ, Tallinn, pp. 25–43 (in Estonian).

Pyne, S.J., Andrews, P.L., Laven, R.D., 1996. Introduction to Wildland Fire. John Wiley, New York, pp. 772.

Raet, J., Sepp, K., Kaasik, A., 2008. Assessment of changes in forest cover-age based in historical maps. For. Stud. 48, 67–78. http://dx.doi.org/10.2478/v10132-011-0056-z.

Reier, U., Tuvi, E.-L., Partel, M., Kalamees, R., Zobel, M., 2005. Threatened herbaceous species dependent on moderate forest disturbances: a neglected target for ecosystem-based silviculture. Scand. J. For. Res. 20, 145–152. http://dx.doi.org/10.1080/14004080510042128.

Reintam, L., Moora, T., 1983. Influence of slash-and-burn cultivation on soil. In: Man, Vegetation and Soil. Estonian Academy of Science, pp. 145–153 in Russian.

Reitalu, T., Seppä, H., Sugita, S., Kangur, M., Koff, T., Avel, E., Kihno, K., Vassiljev, J., Renssen, H., Hammarlund, D., Heikkilä, M., Saarse, L., Poska, A., Veski, S., 2013. Long-term drivers of forest composition in a boreonemoral region: the relative importance of climate and human impact. J. Biogeogr. 40, 1524–1534. http://dx.doi.org/10.1111/jbi.12092.

Ruokolainen, L., Salo, K., 2009. The effect of fire intensity on vegetation succession on a sub-xeric heath during ten years after wildfire. Ann. Bot. Fenn. 46, 30–42. http://dx.doi.org/10.5735/085.046.0103.

Rõuk, A.-M., 1995. Human impact on nature. In: Raukas, A. (Ed.), Estonian Nature. Valgus Publisher and Eesti Entsüklopeediakirjastus Publisher, Tallinn, pp. 494–517 (in Estonian).

Sarmela, M., 1987. Swidden cultivation in Finland as a cultural system. Suomen antropologi – Finn. Anthropolog 4, 241–262.

Schimmel, J., Granstrom, A., 1996. Fire severity and vegetation response in the boreal Swedish forest. Ecology 77 (5), 1436–1450. http://dx.doi.org/10.2307/2265541.

Schmidt, M., Mölder, A., Schönfelder, E., Engel, F., Schmiedel, I., Culmsee, H., 2014. Determining ancient woodland indicator plants for practical use: a new approach developed in northwest Germany. For. Ecol. Manage. 330, 228–239. http://dx.doi.org/10.1016/j.foreco.2014.06.043.

Sillasoo, Ü., Poska, A., Seppä, H., Blaauw, M., Frank, M., Chambers, F.M., 2009. Linking past cultural developments to palaeo-environmental changes in Estonia. Veg. Hist. Archaeobot. 18, 315–327. http://dx.doi.org/10.1007/s00334-008-0210-6.

Sköld, E., Lagerås, P., Berglund, B.E., 2010. Temporal cultural landscape dynamics in a marginal upland area: agricultural expansions and contractions inferred from palynological evidence at Yttra Berg, southern Sweden. Veg. Hist. Archaeobot. 19, 121–136. http://dx.doi.org/10.1007/s00334-009-0234-6.

Stefańska-Krzaczek, E., Zygmunt, Kącki Z., Szypuła, B., 2016. Coexistence of ancient forest species as an indicator of high species richness. For. Ecol. Manage. 365, 12–21. http://dx.doi.org/10.1016/j.foreco.2016.01.012.

Tarand, A., Jaagus, J., Kallis, A., 2013. Estonian climate in past and present. University of Tartu Press, Tartu, pp. 632 (in Estonian).

Tomson, P., 2007. The impacts of historical land use on formation of landscapes and biotypes and development of the protection regime in Karula National Park. Thesis of MSc. Estonian University of Life Sciences, Tartu, 145 pp. (in Estonian).

Tomson, P., Bunce, R.G.H., Sepp, K., 2015. The role of slash and burn cultivation in the formation of southern Estonian landscapes and implications for nature conservation. Landsc. Urban Plan. 137, 54–63. http://dx.doi.org/10.1016/j.landurbplan.2014.12.015.

Tomson, P., Bunce, R.G.H., Sepp, K., 2016. Historical development of forest patterns in former slash and burn sites in Southern Estonia. In: In: Angoletti, M., Emanueli, F. (Eds.), Biocultural Diversity in Europe, Environmental History, vol. 5. Springer, Switzerland, pp. 303–318. http://dx.doi.org/10.1007/978-3-319-26315-1_16.

Uotila, A., Kouki, J., 2005. Understorey vegetation in spruce-dominated forests in eastern Finland and Russian Karelia: successional patterns after anthropogenic and natural disturbances. For. Ecol. Manage. 215 (1–3), 113–137. http://dx.doi.org/10.1016/j.foreco.2005.05.008.

Van Reeuwijk, L.P. (Ed.), 2002. Procedures for Soil Analysis. International Soil Reference and Information Centre, Wageningen, The Netherlands, pp. 101.

Vanha-Majamaa, I., Lilja, S., Ryömä, R., Kotiaho, J.S., Laaka-Lindberg, S., Lindberg, H., Puttonen, P., Tamminen, P., Toivanen, T., Kuuluvainen, T., 2007. Rehabilitating boreal forest structure and species composition in Finland through logging, dead wood creation and fire: the EVO experiment. For. Ecol. Manage. 250 (1–2), 77–88. http://dx.doi.org/10.1007/978-3-319-26315-1_16.

Vasari, Y., 1992. Botanical and stratigraphic view of the environmental history of Finland. In: Särkkä, J. (Ed.), Suomen muutuva luonto. Mikko Raatikaiselle omistettu juhlakirja, Jyvaskylan Yliopistu, Jyvaskyla, pp. 155–163 (in Finnish).

Verheyen, K., Guntenspergen, G.R., Biesbrouck, B., Hermy, M., 2003. An integrated analysis of the effects of past land use on forest herb colonization at the landscape. J. Ecol. 91, 731–742. http://dx.doi.org/10.1046/j.1365-2745.2003.00807.x.

Viro, P.J., 1974. Effects of forest fire on soil. In: Kozolowski, T.T., Ahlgren, C.E. (Eds.), Fire and Ecosystems. Academic Press, New York, pp. 7–45.

Vorobyova, L.A., 1998. Chemical Analysis of Soils. Moscow University Press, Moscow, pp. 297.

Wulf, M., 1997. Plant species as indicators of ancient woodland in northwestern Germany. J. Veg. Sci 8, 635–642. http://dx.doi.org/10.2307/3237367.

Wulf, M., 2003. Preference of plant species for woodlands with differing habitat continuities. Flora 198, 444–460. http://dx.doi.org/10.1078/0367-2530-00118.

Wulf, M., 2004. Plant species richness of afforestation with different former use and habitat continuity. For. Ecol. Manage. 195, 191–204. http://dx.doi.org/10.1016/j.foreco.2004.02.046.

Żmihorski, M., 2011. Forest inventory data reveal stand history from 115 years ago. Ann. Bot. Fenn. 48, 120–128. https://www.jstor.org/stable/23727893.

IV

Tomson, P., Kaart, T., Sepp, K. Macroscopic charcoal in forest soils in the context of slash and burn cultivation and forest fires. Silva Fennica. Submitted (2018).

Macroscopic charcoal in forest soils in the context of slash and burn cultivation and forest fires

Highlights

- Charcoal from slash and burn cultivation is widespread in boreal forest soils
- Charcoal deposits in forest soils originate from distinct fire events
- The characteristics of soil charcoal assemblages are more strongly connected with soil properties than with previous land use and relief
- Markers additional to soil charcoal are needed for previous land use to be identified

Abstract

Slash and burn cultivation have been widespread in Northern Europe until the beginning of 20th century but charcoal deposits in forest soils have mainly been considered in the context of wildfires. The present study discusses the potential of soil charcoal as an indicator of historical land use.

Study sites were in six Protected Areas in southern Estonia. 19th century land use maps were used to identify the historical land use. Macroscopic (visible) charcoal were studied in 105 soil pits and in six trenches, located in forests, recent forest fire sites, and experimental slash and burn fields. Location in soil profile, species composition and character of charcoal were recorded. 20 charcoal samples were dated.

Soil charcoal associated with historical slash and burn cultivation is widespread in northern Europe. Soil properties, then historical land use and relief, were the principal determinants of charcoal character. In the footslopes, rotational slash and burn cultivation caused the accumulation of humus with dispersed charcoal. In the study sites the charcoal of slash and burn cultivation soils was dated to 15th-19th century AD and the oldest forest fire charcoal was dated at about 6000 years before present.

Patchy spatial distribution and the evident translocation of charcoal from different fire events complicates the interpretation of charcoal pattern. The location of charcoal in the soil profile was found to be a better indicator of historical land use than abundance or fragment size. The species composition of soil charcoal stock could indicate the former land use.

Keywords: swidden agriculture; wildfire, land use history, black carbon

1. Introduction

A knowledge of forest history is now considered necessary for informed decisions on how to manage and protect forests. Slash and burn cultivation (swidden agriculture) is one of the factors which have influenced the forests in Northern Europe. This practice was widespread in Neolithic times in Europe and continued into the 20th century in Finland, Sweden, Latvia, Estonia, Norway and Russia. However, only a few studies on slash and burn cultivation as an influence on present-day European boreal forest habitats have been published, perhaps because of a lack of information about the precise sites where it took place.

Fire history in boreal forests has been studied by dendrochronology (Lehtonen and Huttunen 1997; Lehtonen 1998; Lindbladh et al. 2007; Storaneut et al. 2013) and by examination of the layers of microscopic charcoal in water bodies or peat sediments (Patterson et al. 1987; Clark 1988; Condera et al. 2009; Bradshaw et al. 2010; Sköld et al. 2010). Former slash and burn sites have been identified using historical maps (Tomson et al. 2015; Tomson et al. 2016; Čugunovs.et al. 2017), but suitable maps for designating the extent of slash and burn cultivation sites are not always available or they may cover only a brief historical period. Therefore, complementary indicators are needed to study the forest history at the site level.

The presence of charcoal in soil is used to recognize the sites of former forest fires (Wardle et al. 1998; Ohlson and Tryterud 2000; Carcaillet and Talon 2001). Macroscopic soil charcoal is considered as an indicatorof local burns (Carcaillet 1998; Ohlson and Tryterud 2000; Lynch et al. 2004) and has been utilized to deduce the frequency of forest fires and the historical species composition (Ludemann 2003; Ponomarenko et al. 2013; Robin and Nelle 2014; Robin et al. 2014; Kasin et al. 2017).

Fire frequency is used to detect anthropogenic and natural fires, the former having been found to be more frequent (Fesenmyer and Christensen, 2010, Robin and Nelle, 2014). Lagers and Bartholin (2003) used radiocarbon dating and charcoal stratigraphy to distinguish the charcoal which originated from cultivation. Hokkanen (2006) used the presence of soil charcoal as a sign of slash and burn cultivation. In Sweden Weymark (1968) described soil charcoal in the uppermost layer of mineral soil as a result of slash and burn cultivation.

Soil charcoal have become topical in connection with forest soil fertility and carbon cycle, greenhouse gases and climate changes (Jaffe et al, 2013, Hart and Luckai, 2013). In addition, soil charcoal could affect the carbon sequestration of soil organic material (Pluchon et al. 2016).

Charcoal can persist in soils for very long times, but only a proportion of the charcoal stock is stable (Czimczik and Masiello, 2007; Ohlson et al, 2009). The decomposition rate depends on the original material and the fire regime (Rosengren 2000; Nguyen and Lehmann 2009; Kasin and Ohlson 2013). The main reason for decomposition of charcoal is oxidation (Nguyen and Lehmann 2009). Some charcoal could burn during the next forest fire (Ohlson and Tryterud 2000), this process must concern primarily the surface charcoal. The decomposition of charcoal can also be due to soil microorganisms (Czimczik and Masiello, 2007). Freezing and thawing promote fragmentation of the charcoal; these processes are more effective in the soil surface layers (Carcaillet and Talon 2001; Czimczik and Masiello 2007).

Forest fire may consume the complete soil organic horizon and leave charcoal above the mineral horizon (Ohlson and Tryterud 2000, Czimczik et al. 2005; Ohlson et al. 2009). If the fire is less intense, only part of organic material may be destroyed and charcoal may remain in the organic layer (Czimczik et al. 2005). The spatial variation of charcoal inside the burned area is high and depends on vegetation and soil characteristics (Ohlson and Tryderud, 2000).

Clear correlations have not been found between the age of soil charcoal and measures of amount (Ohlson et al. 2009; Fesenmyer and Christensen 2010), especially in mineral soil (Gavin 2003). The intensity of fire and nature of the vegetation determine the abundance of the resulting charcoal so the present-day soil charcoal stock cannot simply be determined by the time elapsed since the fire (Czimczik et al. 2005; Hart and Luckai 2013).

Translocation, which can be both vertical and horizontal, is a more significant factor in charcoal loss than mineralization (Major et al. 2010). The maximum depths of soil charcoal could be as low as 2 metres (Bobrovsky 2010). Soil bioturbation, erosion and freeze-thaw processes could be factors in the burial of charcoal (Carcaillet 2001). Many authors have stated that in forests the main factor burying charcoal is tree uprooting by wind throw (Bobrovky 2010; Gavin, 2003; Talon et al. 2005), which can give rise to charcoal complexes at depths of 40-80 cm (Bobrovsky 2010). Some authors have cited earthworms as a principal cause of burying charcoal in mineral soil (Carcaillet 2001; Eckemeier et al. 2007; Major et al. 2010).

Charcoal studies have contributed to many fields of science, including the radiocarbon dating of ancient land use. Lageårs and Bartholin (2003) have studied macroscopic charcoal associated with the clearance cairns that are considered diagnostic of cultivation. Charcoal found under field baulks and cairns has been interpreted as the legacy of slash and burn cultivation antedating permanent cropping (Lang, 2007) or other human activity (Kaldre, et al. 2010) in Estonia. The oldest fields in Estonia have been dated to the Middle Bronze Age, 1300–1000 BC (Lang 2007).

Based on various authors' description of slash and burn cultivation (Heinikheimo, 1915, Tarkiainen 2014, Ligi, 1963, Meikar and Uri, 2000), it can be predicted that the charcoal in boreal forest soils could be result of four types of fires, each with characteristic features: rotational slash and burn cultivation in young forests, slash and burn cultivation in old-growth forest, intense forest wildfire and low intensity ground wildfire.

The present study documents the presence and location of charcoal in former slash and burn sites and investigates the potential of soil macroscopic charcoal as a marker of former slash and burn cultivation. The following research questions are posed:

- Are the location, measures of amount and particle sizes of soil charcoal associated with soil characteristics, landscape relief and former land use;
- Are species compositions and ages of soil charcoal deposits associated with historical land use land;
- Are 19th century land use maps reliable information sources for the study of effects of historical slash and burn cultivation;
- Could soil charcoal be used as a marker of former fire cultivation.

2. Methodology

The study was carried out in southern Estonia in Valga and Võru counties in six Protected Areas (Figure 1.). The climate here is moderately continental. The average temperature is -5

°C in winter and 16 °C in summer and annual precipitation approximately 700 mm (Tarand et al., 2013). The soils are mainly sandy and loamy acidic soils covering Quaternary sediment moraines on the Devonian bedrock (Kõlli, 2012). The region is characterized mainly by hilly relief with moraine kames and eskers, but the surroundings of the Pähni study sites are flat, and of Mõisamõtsa, wavy, relief. The relative height of hills is 25-60 m and the slopes reach up to 30º. In this region the first signs of settlement are from Mesolithic times, with signs of cereal cultivation from the Bronze Age (Laul and Kihno 1999).

Soil charcoal was sampled in Karula National Park (69 soil pits); in Pikkjärve (two pits), and Paganamaa Landscape Protection Areas (seven pits), Mõisamõtsa (five pits) and Pähni Nature Protection Areas (three pits); and in Haanja Nature Park (19 pits). In 2014-2015 soil sampling (70 excavations) was conducted as a part of a vegetation survey (Tomson et al. 2018). In 2016, additional soil samples (35) were taken in Karula NP to obtain comparative information from sites with different land use histories.

To identify the land use history the cadastral maps from the 19th century were utilized (Appendix 1). Twelve soil pits were established in former arable fields, 47 pits in former slash and burn sites and 46 in 19th century forest. In 2014–2015, all observed former forest sites (34) were mesic *Oxalis* type forests. In 2016 nine oligo- mesotrophic pine forest sites were added. Six pits were established in historical forest sites, where forest fires took place around 2006. Four pits were made in arable fields coincident with abandoned experimental slash and burn fields, established in 2007 and 2009 by the Estonian National Museum (the experiment is described by Jääts, et al. 2011).

Soil pits (50x50 cm) were excavated as semi-excavations (Astover et al. 2013). The scales to estimate the amount and character of soil charcoal were worked out using five preliminary soil pits, not included in the formal study. Level terrain was preferred in 2014 and 2015 in order to register the soil properties characteristic of the sites. The upper and lower border of layers containing the charcoal, and the borders of layer containing the biggest amount of charcoal, were measured. Charcoal pieces visible in the soil profile and with a linear dimension greater than 0.1–0.2 cm were considered as macroscopic charcoal (Scott, 2010; Wallenius 2002). The charcoal pieces with mineral soil coatings, similar to the soil aggregates were not examined (Ponomarenko et al. 2018). Visual assessment was made of the amount of soil macroscopic charcoal on the scale: no charcoal, a few fragments (single pieces, mostly with diameter 1–2 mm), medium abundance (several pieces of a range of sizes), high abundance (numerous pieces or clusters or sooty layers visible in the pit wall).

The recorded characteristics, their ranges of values and abbreviations are presented in table 1. Presence of charcoal fragments was tabulated on a presence/absence basis, according to five size classes: diameter (cm) 0.1-0.2; 0.2-1.0; more than 1.0; clusters (layers or conglomerates with different size fragments) and dark sooty layer. Size diversity of charcoal fragments was calculated setting aside the last class, a given sample would therefore have a score of 0–4, depending on how many of the size classes were present.

The presence of charcoal with clearly visible structure and without signs of abrasion, and its occurrence under the humus layer, were noted. Study site locations were described according to relief forms (flat area, slope, top of hill and footslope) and the microrelief of each soil pit location was recorded (flat, small incline, greater incline). Thicknesses of litter and humus layers were measured. Signs of bleaching and soil texture were noted. The soil types were identified using the digital Estonian Soil Map (Estonian Land Board, 2017a).

In 12 sites pits were excavated in both the upper and lower (footslope) areas of hills in 2016 to estimate the role of erosion in accumulation of soil charcoal. The structures of eroded soils with charcoal were examined additionally in trenches (55– 65 cm depth, x 120– 160 cm length) in footslopes, established in six (four former slash and burn and two former forest) sites in Karula NP. The trenches extended from the ground surface to the C horizon, to the same, or lower, level as the surrounding area.

For radiocarbon dating, charcoal samples were collected from two layers in five trenches and from four layers in one (the deepest) trench, from soil pits of two former slash and burn cultivation sites (two layers) and two forest sites (one layer). The conventional radiocarbon dating method was applied to the bigger charcoal samples, otherwise accelerator mass spectrometry was used. For calibration the Oxcal 4.3 programme was used.

Charcoal samples were collected for identification of species from the same layers of trenches as for dating. Charcoal samples were collected from 24 soil pits from different depths and pieces larger than 5 mm diameter identified to species using a reference collection and an online version "Wood anatomy of central European Species" (Schoch, et al., 2004).

Historical settlements near the sample sites were identified from the 'Database of archaeological and place-lore sites', developed by the Centre for Archaeological Research and Infrastructure, Institute of History and Archaeology, University of Tartu.

For statistical analyses the sites were grouped according to land use and to time period (before the 19th century, 19th century, 20th century and 21st century). Seven sites had been mapped as forest in the 19th century but included field banks characteristic of cultivation and therefore were defined as period "before 19th century" and these sites were grouped together with slash and burn sites. To identify the early 20th century land use, after the decline of slash and burn cultivation, the one-verst topographical map from 1912 to 1922 was used (Estonian Land Board, 2017b). Land use classes in the 21st century were open vegetation (former arable fields covered by grasslands); forest; experimental slash and burn sites; and recent forest fire sites. Sites of the two last-named classes were not used in the univariate analyses of sites of earlier time periods, in order to avoid biased results.

All statistical analyses were performed with R 3.3.3 software and results were considered statistically significant at $p \leq 0.05$. Permutation analysis of variance (ANOVA) with the function 'oneway_test' was applied to compare the charcoal variables in land use groups. The analyses were performed separately for land use groups corresponding to different centuries. The permutation test for dependent samples with function 'independence_test' was used to compare charcoal variables in the upper and lower regions of hills. Both used permutation tests included in the 'coin' R package. Spearman correlation analysis was performed to study the relationships between charcoal, relief and soil characteristics. Principal component analysis (PCA) was used to discover basic patterns in charcoal data and to study the relationships of these patterns with land use groups at different times. Variance partitioning analysis (VPA) was used to estimate the unique and shared components of the variance of charcoal characteristics related with land use at different centuries, soil and relief characteristics. Additionally another VPA was performed considering land use groups at different centuries as separate variables and estimating their relative importance in relation with charcoal data. For better visualization of VPA results the proportional Euler diagrams were fitted using function 'eulerr'. Redundancy analysis (RA) followed by a permutation test was used to test the statistical significance of land use, soil and relief characteristics. The PCA was performed with function 'dudi.pca' in the 'ade4' package, and VPA and RA were performed with the functions 'varpart' and 'rda' in the 'vegan' package.

3. Results

Charcoal was found in 102 observed sites (97.1%) in sites with different land use history (Table 2).The greatest average depths of charcoal (40.6 cm) were found in former arable fields, now with open vegetation. The experimental slash and burn field and forest fire sites are characterized by presence of charcoal in upper layers (average minimal depths 2.0 and 1.5

cm, respectively). When comparing the charcoal location according to humus layer, the highest position is associated with recent forest fires (average depth 2.8 cm) because charcoal was also found in the litter layer. The soil layer containing charcoal pieces was thickest in recent forest fire sites (average depth 30.2 cm), but this statistical significance was found only when comparing land uses in the 21st century. Charcoal-rich layers were at the highest position (average depth 2.3 cm) in experimental slash and burn fields and deepest in arable fields (average depth 38.8 cm). With reference to 19th century land uses, the charcoal-rich layer was located deeper in arable fields, than in slash and burn sites and also in forests. The thicknesses of the charcoal layers were not statistically different.

There were no significant differences in amount of charcoal and in the presence of the different diameter classes, between sites with different land use histories, and the charcoal was always found under the humus layer. An undisturbed structure of the charcoal fragments more evident in recent forest fire sites and experimental slash and burn sites, but these differences were not significant comparing the land use in the 19th century and before. The relief and micro-relief were similar in sites with different land use history. The thickness of litter and humus layer were significantly different between sites with different land use history, while the other soil characteristics did not reveal significant differences.

When comparing the hill tops and footslopes charcoal was found deeper in the footslopes, but only at $p = 0.067$ (Table 3). Charcoal was more abundant in the footslopes. Also charcoal pieces greater than 1 cm in diameter, clusters and charcoal with visible structure were more frequent in footslopes. The humus layer was thicker in footslopes.

In former arable fields charcoal of spruce origin was of more frequent occurrence; in forests and former slash and burn sites, pine, but spruce charcoal was also frequent (Table 4).

Charcoal of other tree species did not show significant differences in these respects due to small sample sizes, but deciduous species were possibly more evident in slash and burn sites. Analysis of data from trenches revealed that charcoal not of round-wood origin was more frequent in forest sites.

Variance partitioning analysis (Figure 2) demonstrated that altogether 52.0% of the variation in charcoal characteristics is explained by soil properties, relief and land use in different centuries. There is quite a big overlap of soil properties and land use history effects (Figure 2A). However, 21.4% of charcoal variation was explained only by soil properties and 9.9% byland use history. The relief effects were lower and almost totally explained by soil and land use. Grouping the periods, land use effects explained 28.8 % of charcoal variation. The strongest effect was due to 21st century land use, which alone explained 24.3% of charcoal variation. The effects of land use in earlier centuries were 8.0–10.3%, overlapping with each other and with 21st century land use (Figure 2B). This result demonstrates the stability of land use during different time periods.

Redundancy analysis also revealed the strong effect of 21st century land use on charcoal characteristics ($p < 0.001$), the other variables with $p < 0.1$ in the model were soil type ($p = 0.013$) and texture ($p = 0.065$).

The PCA revealed that 55.3% of charcoal variation could be described by the first two factors. The first component was mostly determined by location of charcoal in the soil, the second component by charcoal size, character and amount (Figure 3A). Land use in 19th century is related to charcoal location and the more obvious differences were between sites used as arable lands and other sites (Figure 3B). These differences would be even clearer if the experimental slash and burn sites (located in arable lands) were omitted. The 21st century arable lands were distinguished also in the direction of the first factor (charcoal location), but additionally the sites with experimental slash and burn cultivation and recent forest fires differ in the direction of the second component, indicating that better preserved, more diverse and bigger amounts of charcoal particles were found in these sites (Figure 3C).

The Spearman correlations between charcoal characteristics and relief conditions were weak (Table 5). The litter and humus thicknesses were positively correlated with charcoal depth characteristics. Charcoal was found deeper and the layer with charcoal was thinner on average in fertile loamy soils but correlations were quite weak. Sandy soils were more strongly associated with thick charcoal-containing layers and with presence of pieces in different size groups. In the poor soils, sooty layers and charcoal under the humus layer were found more frequently. When the charcoal was in a higher position or a sooty layer was present, the signs of bleaching were more evident.

The results of radiocarbon dating of charcoal samples are presented in Table 6. The oldest charcoal was dated 4940±50 BP, in a forest site, and the youngest, in a former slash and burn site, 95±30 BP. The age of charcoal increased with depth except in accumulated humus in a former slash and burn cultivation site in Mähkli. Numerous calibrated dates may extend out of range, mainly the dates of charcoal from humus in former slash and burn sites but also in the Pehme forest site. The observed sites were located 0.2-3.3 km from nearest historical settlement. The oldest settlement near the excavated trenches is in Mähkli (Pre-Roman Iron Age).

The dates of charcoal from Koobasaare soil pit correlates well with the dates of charcoal collected from the trench in the same site. In this soil pit the charcoal in the humus layer was dated from 1682 to the present time and in the humus layer in the field bank of the same site the charcoal was dated from 1652 to the present time. In the illuvial layer of the soil pit the charcoal was dated 1026-1182 AD and in the the lower layer in field bank, 1017-1221.

4. Discussion

The presence of charcoal in most sample pits in this study confirms the general finding that charcoal is widespread in soils of the boreal region. Considering how widespread swidden agriculture was in northern Europe (Heikinheimo, 1915; Ligi, 1963; Weimarck 1968), an important part of the soil charcoal stock must originate from slash and burn cultivation. This study has focused on whether the location of charcoal in the soil, and its amount, character and species composition, can indicate whether fire cultivation had taken place. We also consider how effects of fire cultivation can be distinguished from those of forest fires, and how these natural and anthropogenic events can be dated.

Occurrence of the charcoal in the soil profile did not differ between 19th century forest sites and former rotational slash and burn fields in the present study and therefore could indicate either type of former land use. Analyse the land use "before 19th century" did not reveal additional differences from ealier times.

4.1. Location of charcoal in soils

As would be expected, charcoal was located in the highest positions in experimental slash and burn fields and sites of recent forest fires. Also, the results of variance partitioning analysis demonstrated that the effect of 21st century fires had been the strongest and the older land use had smaller effects. In old burned sites the charcoal was found much deeper, and this is explained by translocation. In 19th century slash and burn cultivation sites charcoal on average was found deeper than in 19th century forest land. Considering that after cultivation litter is not present on the soil surface, the charcoal depth in relation to the humus layer is informative. In recent fire sites the charcoal-rich layer was located deeper than charcoal from the most recent burning and therefore must originate from earlier fires.

In coniferous forests, charcoal would be expected to remain in the organic litter layer or at the surface of the mineral layer after a fire (Czimczik and Masiello 2007). Any charcoal left at ground level must have mostly decomposed, because in 19th century forest sites charcoal were not found in litter, and only in nine places, none of which had been burned in the 21st, century, was it found on top of the mineral soil. The charcoal in the litter may pass downwards over time due to the degradation of the litter from beneath. Therefore the depth of charcoal must be examined in relation to the mineral soil. The process causing the decomposition and fragmentation of charcoal is more active in well aerated conditions (Nguyen and Lehmann 2009), which might explain, why charcoal was not found in the litter layer of 19th century forest sites.

The physical opening of the ground, such as would follow treefall, is one possibility, and treefall is associated with intense forest fires. Talon et al. (2005) even stated that unless there is tree uprooting, historic forest fires are relatively unlikely to be recorded on the basis of presence of soil charcoal. Bobrovsky (2010) observed that after fire the ground is opened and charcoal is washed into the front and back side of windfall depressions to a depth of 40-80 cm, forming clusters or layers. In the present study charcoal was found in a wide range of depths down to 50 cm, and in forest sites the average maximum depth was less than in other land use groups, and probably not deep enough for uprooting to have been the cause.

In the general areas where the present study was conducted, extensive uprooting of trees immediately after fires, has not been noted. In the burnt places the pines have mostly survived, the spruces have been affected by fire, but have died out gradually during the time, when ground surface was covered by vegetation that blocked the water flow on soil surface.

Therefore, the accumulation of charcoal into treefall pits could be not so important here. Pieces of charcoal could be buried in the process of soil falling from uprooted root collars after fire and this would disperse forest fire charcoal into higher positions than treefall depressions. Repeated uprooting in the same place could translocate the charcoal many times.

In fire-prone habitats with infertile podzols, the charcoal layer was thick with pieces of a wide range of sizes, probably the result of ground fires. Microscopic fractions of charcoal could probably infiltrate mineral soils, assisted by freeze and thaw and the effect of roots (Gabet et al. 2003). Wild boar could affect the superficial layers too, as 67% of stands sampled in 2014–2015 were in some extent damaged by these animals, no differences being found between former slash and burn sites and forests (Tomson et al. 2018).

In most fire prone forests in podzols the water absorption is good and erosion of slopes is considered unlikely to result (Kõlli, 2012). Ground fires are in general unlikely to result in erosion, unless litter is destroyed. In contrast, in the case of stand-replacing intense forest fires the surface could be exposed and erosion could proceed, probably in an uneven pattern. Eroded charcoal is more likely to accumulate in micro depressions than to be lost from the slope (Bobrovsky 2010). The oldest charcoal found in the present study, from a depth of 33 cm, may have accumulated into clusters in this way, as a result of water flow.

The mechanisms by which the charcoal is mixed into the soil differed in the case of slash and burn cultivation. As the most deeply located charcoal was found in former arable fields, tillage must be an important translocating factor. Tillage causes soil redistribution and erosion not only by opening the soil to the water but also by causing the soil to move horizontally in slopes (Govers et al. 1994; Van Oost et al. 2000) thus burying the charcoal. In arable fields the deep location of charcoal is because the charcoal derived from initial land clearance with fire or resulting from preceding slash and burn cultivation, has been buried by annual tillage over many hundred years. But the finds of charcoal at depths of 50 cm even on hilltops in cultivated sites suggest that the signs of forest fires and subsequent bioturbation from the time before tillage, could remain in the soil profile and probably charcoal from pre-cultivation forest fires is still to be found in the slash and burn fields.

The field banks associated with former slash and burn cultivation sites on slopes result from tillage erosion. In Sweden and Finland field banks or terraces, formed by the soil accumulation due to tillage erosion are of prehistoric origin (Maaranen 2002; Widgren 2010). The main body of a field bank typically consists of accumulated humus with dispersed charcoal (Figure 4). The accumulation of humus is connected with rotational slash and burn cultivation because recovering stadia with grass vegetation and deciduous trees promoted humus formation, and burning and cultivation provide the scattered charcoal. Accumulations of this kind were not observed in the trenches soil profile of two former forest sites (Figure 5). Different periods of cultivation opening the soil surface have led to the formations of different charcoal rich humus layers in Alakonnu and Mähkli; in Karsi and Koobassaare this pattern was not so obvious.

The former slash and burn fields were ploughed and harrowed for some years after burning. The soil was mixed and charcoal was buried in the soil. In recent slash and burn sites the upper part of the humus layer was darker with most charcoal at average depths 2.3-9.5 cm, consistent with the depth of ploughing with traditional ploughs (5-10 cm; Pärdi 1998). In former slash and burn sites now covered by forests the depth of charcoal is greater because the mineral soil is covered by litter about 5 cm in average. In case of slash and burn cultivation the layers of charcoal are unlikely because the soil is mixed, but still the clusters of charcoal were found in former forest sites and arable fields alike. Tillage did not mix the soil evenly. Eckmeier et al (2007b) have described, that the spatial distribution of charcoal on surface was very variable after burning in experimental slash and burn cultivation.

Water was considered the important factor in charcoal transportation downhill (reviewed by Scott, 2010). Larger particles of charcoal could be transported further than small fragments and charcoal could sediment out downstream as assemblages of particles of comparable sizes (Nichols et al., 2000). This effect was also demonstrated in the present study, as the large particles, clusters and charcoal with well maintained structure were found more in footslopes. The water erosion of charcoal must have taken place when the surface was opened, but the charcoal would not have been mixed into soil when forest fires were intense, and even less in the case of slash and burn cultivation in old forests. The trenches revealed that sooty layers with charcoal were accumulated in the transition zone from slope to flat, both in slash and burn and forest fire sites. These layers in slash and burn sites are located in lower positions and therefore could indicate previous forest fires.

In many cases the charcoal location could not be explained by ploughing depth and results of erosion, therefore other mechanism of transportation must be considered. In case of regular slash and burn cultivation tree uprooting is unlikely, because of the young ages reached by trees in land used for this purpose (Ligi, 1963, Tarkiainen, 2014). The possible interaction between earthworms and charcoal is still unclear (Weyers and Spokas 2011). Carcaillet (2001) suggested anenic earthworms move the charcoal deeper into mineral soils. Also in field experiments, charcoal has been incorporated into the soil profile mainly by earthworms (Eckemeier et al. 2007; Major et al. 2010). Charles Darwin's famous experiment, showed that worms sank the small pieces of coal into soil over a period of 20-30 years (Darwin, 1881). Terhivuo (1989) found that in boreal coniferous forests the number of individuals, biomass and number of earthworm species is much lower than in meadows and deciduous forests. In coniferous forests the activity of earthworms is limited to the litter layer. In case of rotational slash and burn cultivation the land were covered with grassland and deciduous trees most time and therefore the activity of epigeic earthworms must have been more intense than in continuous forest land with coniferous forests. That may explain why the charcoal was found in the humus layer. Other invertebrates and plant roots are also known to contribute to soil bioturbation (Gabet et al, 2003).

4.2. Amount of charcoal as an indicator of land use

The amounts of charcoal were found not to differ in former slash and burn sites and forest sites. Differences would have been expected due to the different fire regimes. A single forest fire event produces 235 to 735 kg of charcoal per hectare on average (Clark et al. 1998; Ohlson and Truderud 2000) and the amounts of charcoal produced vary according to fire intensity. In slash and burn cultivation experiments in Germany about 5,200 kg of charcoal per hectare were produced (Eckmeier et al. 2007b). Ohlson and Truderud (2000) demonstrated, that if all forest fire charcoal had been maintained in soil, the amount of charcoal in the environment would be much larger than it actually is.

In boreal forests the interval between the fires is approximately 80 years (Niklasson and Granström 2000; Rolsdat et al. 2017). Forest fires have happened periodically over thousands of years. The rotation intervals in cultivation was approximately 20 years and rotational slash burn cultivation has been known for centuries (Ligi 1963; Jääts et al. 2010).

The present study is in agreement with those of Cimzik et al. (2005), that in forest fires most charcoal is left in the litter layer and therefore exposed to subsequent fires. In slash and burn cultivation the charcoal is mixed into the soil and protected from pyrolysis. The slash and burn experiment conducted in Karula in 2009 showed that during the first burning the maximum temperatures at 1 cm depth were 104.7º C, at 3cm, 80.6º C; at 6 cm, 47 º C; at 10 cm, 34.7º C and in the second burning at 1 cm depth 139.7 º C; at 3cm, 88.7 º C; at 6 cm, 70.8 º C and at 10 cm, 45.4º C (unpublished data, Estonian National Museum). These temperatures are too low to ignite charcoal in soil, especially in conditions of shortage of oxygen. Therefore it is not likely that subsequent burning consumes much of the charcoal from previous burnings, so in slash and burn land more charcoal could accumulate than in forest soil. The present study suggests that in terms of charcoal accumulation the longer fire history of forests has been balanced by better preservation of charcoal in slash and burn sites.

Also translocation changes the amount of charcoal. The amount of charcoal did not correlate with relief in correlation analysis or variance partitioning analysis because of high variability of charcoal content, but comparison of the upper and lower parts of the same slope revealed, that the amount of charcoal is determined by relief, causing the accumulation of charcoal in the lower parts of relief. The same effect was found in trenches.

The identification of charcoal amount and layers during vegetation surveys is problematic due to the small size of soil analysis pits and because of the large spatial variability of charcoal in burned areas. The trenches in the footslopes are more reliable indicators due to better developed charcoal accumulation structures.

4.3. Size and character of charcoal particles

Univariate analysis did not demonstrate differences between 19th century land use groups in size of charcoal particles. Principal component analysis demonstrated that the presence of fragments of different size classes were most strongly associated with recent burnings.

Relatively large pieces and conglomerates of charcoal were also found in arable fields, indicating that the expected mechanical abrasion due to tillage (Ponomarenko and Anderson 2013) did not prevail and charcoal could persist in the soil even with regular ploughing and harrowing. Charcoal clusters were found equally in former slash and burn and forest sites, though in the case of cultivation the clusters would have been expected to be destroyed.

In some sites dark smeary soot-like layers were found. This kind of microscopic charcoal could probably be formed in the burn layer of smaller organic particles like moss and litter or peat. In case of rotational slash and burn cultivation the formation of microscopic non-wood charcoal must be limited, because in young deciduous forest the litter layer is thinner than in old coniferous forest. The sooty layers were not found to be different in former forests and slash and burn sites, but PCA and correlation analysis showed that the sooty layers are to some degree connected with poor soils and therefore this could be characteristic of the forest fires of infertile pine forests. A dark grey colour, due to microscopic charcoal, was also observed in soil profiles of dry pine forest sites. This kind of layer was also present in the bottom parts of trenches. The wavy layers, formed by flowing water in micro-depressions were found only in trenches, in the transition from footslope to toeslope.

4.4. Species composition of soil charcoal in relation to historical land use

In the present study, more charcoal of spruce origin was found in former arable fields. These results are consistent with the results of pollen analyses in the Karula region, demonstrating the recession of the spruce at the time of agricultural expansion (Poska et al. 2017). Deciduous trees were more common in slash and burn sites than in forests but because of the small number of charcoal fragments statistical difference was not found. These results are consistent with historical descriptions of slash and burn cultivation (Ligi 1963; Meikar and Uri 2000). Pine charcoal was more common in forests, but was also quite frequent in slash and burn sites. The pine charcoal might have been from the first burning in mature forest, mixed into the humus layer, but it is also possible that the tree cover of rotational slash and burn land included pines. Pine charcoal was most common, therefore the question about better preservation of pine charcoal needs future attention. Relative abundances of tree species deduced from charcoal assemblages is not strictly accurate, because tree species produce different proportion of charcoal and charcoal with different properties (Braadbaart and Poole 2008; Fréjaville et al. 2013). Fire resistance of forests also varies; spruce forests are less fire-prone than pine forests (Tryterud 2003; Wallenius et al. 2005).

The non- roundwood charcoal, found in the lower parts of trenches, could be the result of forest fire, where the main source of charcoal must be the ground vegetation, litter, bark and cones. In recent forest fire sites numerous burnt cones were found in the litter. Probably this kind of charcoal is more indicative of low intensity ground fires. But non-roundwood charcoal was also found in the humus layer of former slash and burn cultivation sites indicating the complexity of interpretation of charcoal assemblages.

4.5. Dates of fire events

In most dated sites the upper layer consisted of younger charcoal. In field bank trenches the correlation between the depth and age of charcoal was evident, because eroded soil is accumulated in distinct, successive layers. The only exception was Mähkli trench, where the lower humus layer were dated younger in average.

Charcoal from the upper layers of former rotational slash and burn was dated to the period from the 15th century to the end of the 18th or beginning of the 19th century. These dates correlate with the period of widespread slash and burn cultivation described in Estonian literature (Ligi 1963; Tarkiainen 2014). They also coincide with a period of increased anthropogenic fires in Nordic countries (Niklasson and Granström 2000; Wallenius 2011; Storaunet et al. 2013). In the humus layer of slash and burn soils were found mixtures of charcoal probably from different burnings, as demonstrated by the dates from Mähkli humus layers.

To interpret the charcoal radiocarbon dates the inbuilt age error must be considered and the real burning time belongs to a later time than shown by the dated charcoal (Gavin, 2001). In case of rotational slash and burn cultivation the inbuilt age error could not be noticeable, because the trees were approximately 20 years old when burned (Jääts et al. 2010). In the case of earlier cultivation in mature forests and forest fires the inbuilt error could be bigger due to the age of burned trees because stem wood and old branches had burned. Spruce and pine may reach ages up to 400 years in Estonia (Etverk, 1974; Kollist, 1974). Also the time must be considered of the decomposition of coarse woody debris, which is more exposed to wildfire than growing trees. This period is within 65–90 years in studied region (Krankina and Harmon 1995), therefore the maximum inbuilt error could reach up to 600 years. As the dated samples did not consist only of pieces of stem wood charcoal, and the weighted average age of burned material is used for the dating of assemblages, the actual inbuilt error is lower than calculated maximum.

The lower charcoal layers, dating back thousands of years, mark natural forest fires. Archaeological investigations from neighbouring areas suggest that mixed transitional layers, consisting bleached soil, some humus-like material and charcoal rich soil (weighted average dates in Karsi 747 AD, Mähkli 980 AD) could mark the first use of the old forest for slash and burn cultivation. The late charcoal (1672 AD) in the eluvial soil horizon of Pehme trench belong (taking account of the inbuilt error) to the period when slash and burn cultivation in old forests was restricted and therefore is more likely to be the result of forest fires. At the Rabasaar site (1582 AD) charcoal located in the dark grey mixed eluvial layer could be the result of a single slash and burn cultivation event in mature forest as there is no humus layer. Considering the inbuilt age error and the legal restrictions of the period, the field could have been in use at the beginning of the 17th century. The fire events in Kautsi tee were estimated to be forest fires because of the age of charcoal and distance from settlement. Also no signs of soil mixing were identified.

5. Conclusions

Charcoal is very widespread in boreal soils and this study shows that a considerable proportion can originate from historical slash and burn cultivation. The results demonstrated, that the presence or amount of macroscopic charcoal in forest soil is not a simple visual indicator for distinguishing natural wildfires from slash and burn cultivation. Charcoal variability depended more on the soil properties than on the land use. That the charcoal could originate from different fire events and large spatial variation complicates the interpretation of data. The 19th century land use maps are valuable information sources, but the use of some sites for slash and burn cultivation before the 19th century could remain undetected because a single period of cultivation in mature forests had not left visible traces in the landscape. Statistical analysis has demonstrated that patterns can only be deduced if a variety of analytical methods is used. A combination of different charcoal characteristics and other features of the soil profile may be more effective.

The charcoal was located in the highest position in the case of recent fires and this demonstrates, that during the intervening time charcoal translocation must have taken place. The location of macroscopic charcoal in the soil profile conveys more information about land use history than the amount of macroscopic charcoal. The differences were most obvious in the former arable fields. Cultivation promotes the translocation of charcoal throughout humus layer because of soil mixing, but it also generates suitable living conditions for earthworms and other soil organisms that cause bioturbation. Sharply defined layers of charcoal, the result of water flow, are a characteristic feature of historic forests. Sooty layers in the soil profile is characteristic of wildfires in dry pine forest.

The species composition of charcoal was correlated with historical land use. Radiocarbon dating distinguished of forest fire charcoal thousands of years old in the lower layers from slash and burn cultivation charcoal in humus horizon. The interpretation of intermediate dates needs additional information about settlement history, and to use soil charcoal to determine site land use history needs an integrated approach.

References

Astover A., Reintam E., Leedu E., Kõlli R. (2013). Muldade väliuurimine [Field Study of Soils]. Eesti Maaülikool, Tartu. 70 p.

Bobrovsky M. (2010). Forest soil in European Russia: biotic and anthropogenic factors in pedogenesis. KMK Scientific Press, Moscow. 359 p. [in Russian with English summary].

Braadbaart F., Poole I. (2008). Morphological, chemical and physical changes during charcoalification of wood and its relevance to archaeological contexts. Journal of Archaeological Science 35: 2434–2445. http://dx.doi.org/10.1016/j.jas.2008.03.016.

Bradshaw R.H.W., Lindbladh M., Hannon G.E. (2010). The role of fire in southern Scandinavian forests during the late Holocene. International Journal of Wildland Fire 19(8): 1040–1049. http://dx.doi.org/10.1071/WF09108.

Carcaillet C. (1998). A spatially precise study of fires, climate and human impact within the Maurienne valley, North French Alps. Journal of Ecology 86: 384–396. http://dx.doi.org/10.1046/j.1365-2745.1998.00267.x.

Carcaillet C. (2001). Are Holocene wood-charcoal fragments stratified in alpine and subalpine soils? Evidence from the Alps based on AMS 14C dates. The Holocene 11(2): 231–242. http://dx.doi.org/10.1191/095968301674071040.

Carcaillet C., Talon B. (2001). Soil Carbon Sequestration by Holocene Fires Inferred from Soil Charcoal in the Dry French Alps. Arctic, Antarctic, and Alpine Research 33(3): 282–288. http://dx.doi.org/10.2307/1552235.

Clark J.S. (1988). Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. Quaternary Research 30: 67–80. http://dx.doi.org/10.1016/0033-5894(88)90088-9.

Conedera M., Tinner W., Neff C., Meurer M., Dickens A.F., Krebs P. (2009). Reconstructing past fire regimes: methods, applications, and relevance to fire management and conservation. Quaternary Science Reviews 28: 435–456. http://dx.doi.org/10.1016/j.quascirev.2008.11.005.

Čugunovs M., Tuittila E.-S., Sara-Aho I., Pekkola L., Kouki J. (2017). Recovery of boreal forest soil and tree stand characteristics a century after intensive slash-and-burn cultivation. Silva Fennica 51(5): 1–19. http://dx.doi.org/10.14214/sf.7723.

Czimczik C.I., Masiello C.A. (2007). Controls on black carbon storage in soils. Global biogeochemical cycles 21, GB3005. http://dx.doi.org/10.1029/2006GB002798.

Czimczik C.I., Schmidt M.W.I., Schulze E-D. (2005). Effects of increasing fire frequency on black carbon and organic matter in Podzols of Siberian Scots pine forests. European Journal of Soil Science 56: 417–428. http://dx.doi.org/10.1111/j.1365-2389.2004.00665.x.

Darwin C. (1881). The Formation of Vegetable Mould Through the Action of Worms. London: John Murray. 5th thousand. http://darwin-online.org.uk/EditorialIntroductions/Freeman_VegetableMouldandWorms.html. [Cited 19 Jan 2018].

Eckmeier E., Gerlach R., Skjemstad J.O., Ehrmann O., Schmidt M.W.I. (2007a). Minor changes in soil organic carbon and charcoal concentrations detected in a temperate deciduous forest a year after an experimental slash-and-burn. Biogeosciences 4: 377–383. http://dx.doi.org/10.5194/bg-4-377-2007.

Eckmeier E., Rösch M., Ehrmann O., Schmidt M.W.I., Schier W., Gerlach R. (2007b). Conversion of biomass to charcoal and the carbon mass balance from a slash-and-burn experiment in a temperate deciduous forest. The Holocene 17(4): 539–542. http://dx.doi.org/10.1177/0959683607077041.

Estonian Soil Map (Estonian Land Board, 2017a). xgis.maaamet.ee. [Cited in 20 Dec 2017].

Estonian Land Board Web Map Server Historical Map Application (Estonian Land Board, 2017b). xgis.maaamet.ee. [Cited in 20 Dec 2017].

Fesenmyer K.A., Christensen N.L. (2010). Reconstructing Holocene fire history in a southern Appalachian forest using soil charcoal. Ecology 91(3): 662–670. http://dx.doi.org/10.1890/09-0230.1.

Fréjaville T., Carcaillet C., Curt T. (2013). Calibration of charcoal production from trees biomass for soil charcoal analyses in subalpine ecosystems. Quaternary International 289(15): 16–23. http://dx.doi.org/10.1016/j.quaint.2012.02.043.

Gabet E.J., Reichman O.J., Seabloom E.W. (2003). The effects of bioturbation on soil processes and sediment transport. The Annual Review of Earth and Planetary Science 31: 249–273. http://dx.doi.org/10.1146/annurev.earth.31.100901.141314.

Gavin D.G. (2001). Estimation of Inbuilt Age in Radiocarbon Ages of Soil Charcoal for Fire History Studies. Radiocarbon 43(1): 27–44. http://dx.doi.org/10.1017/S003382220003160X.

Gavin D.G. (2003). Forest soil disturbance intervals inferred from soil charcoal radiocarbon dates. Canadian Journal of Forest Research 33: 2514–2518. http://dx.doi.org/10.1139/x03-185.

Govers G., Vandaele K., Desmet P., Poesen J., Bunte K. (1994). The role of tillage in soil redistribution on hillslopes. European Journal of Soil Science 45(4): 469–478. http://dx.doi.org/10.1111/j.1365-2389.1994.tb00532.x.

Hart S., Luckai N. (2013). Charcoal function and management in boreal ecosystems. Journal of Applied Ecology 50: 1197–1206. http://dx.doi.org/10.1111/1365-2664.12136

Heikinheimo O. (1915). Kaskiviljelyn vaikutus Suomen metsiin. [The impact of swidden cultivation on forests in Finland]. Metsähallituksen julkaisuja II. Keisarillisen senatiin kirjapainossa, Helsinki. 264 p. [In Finnish].

Hokkanen J.P. (2006). Environmental patterns and gradients in the vascular plants and bryophytes of eastern Fennoscandian herb-rich forests. Forest Ecology and Management 229: 73–87. http://dx.doi.org/0.1016/j.foreco.2006.03.025.

Jaffé R., Ding Y., Niggemann J., Vähätalo A.V., Stubbins A., Spencer R.G.M., Campbell J., Dittmar T. (2013). Global Charcoal Mobilization from Soils via Dissolution and Riverine Transport to the Oceans. Science: 340–345. http://dx.doi.org/10.1126/science.1231476.

Jääts L., Kihno K., Tomson P., Konsa M. (2010). Tracing fire cultivation in Estonia. Forestry Studies 53: 53–65. http://dx.doi.org/10.2478/v10132-011-0089-3.

Kaldre H., Aguraiuja Ü., Livin L. (2010). Preliminary Investigations of Fossil Field Systems at Loo. Archaeological Fieldwork in Estonia 2009: 73–82. http://www.arheoloogia.ee/ave2009/AVE2009_Kaldrejt.pdf. [Cited 19 Jan 2018].

Kasin I., Ellingsen V.M., Asplund J., Ohlson, M. (2017). Spatial and temporal dynamics of the soil charcoal pool in relation to fire history in a boreal forest landscape. Canadian Journal of Forest Research, 47(1): 28–35. http://dx.doi.org/10.1139/cjfr-2016-0233.

Kasin I., Ohlson M. (2013). An experimental study of charcoal degradation in a boreal forest. Soil Biology & Biochemistry 65: 39–49. http://dx.doi.org/10.1016/j.soilbio.2013.05.005.

Krankina O.N., Harmon M.E. (1995). Dynamics of the dead wood carbon pool in Northwestern Russian boreal forests. Water, Air and Soil Pollution 82: 227–238. http://dx.doi.org/10.1007/BF01182836.

Kõlli R. (2012). Eesti mullad [Estonian soils]. In: Astover A., Kõlli R., Roostalu H., Reintam E., Leedu E. (eds.) Mullateadus [Soil Science]. Eesti Maaülikool, Tartu. p. 306–398. [In Estonian].

Lageårs P., Bartholin T. (2003). Fire and stone clearance in Iron Age agriculture: new insights inferred from the analysis of terrestrial macroscopic charcoal in clearance cairns in Hamneda, southern Sweden. Vegetation History and Archaeobotany 12: 83–92. http://dx.doi.org/10.1007/s00334-003-0012-9.

Lang V. (2007). Muistsed maakasutussüsteemid Eestis [Ancient land use systems in Estonia]. Ajalooline Ajakiri 3–4: 291–320. http://ojs.utlib.ee/index.php/EAA/article/view/317/312. [Cited 19 Jan 2018].

Laul S., Kihno K. (1999). Prehistoric Land Use and Settlement History on the Haanja Heights, Southeastern Estonia, with Special Reference to the Siksali-Hino Area. In: Miller U., Hackens T., Lang V., Raukas A., Hicks S. (eds.) Environmental and Cultural History of the Eastern Baltic Region. PACT, vol. 57. p. 239–254.

Lehtonen H., Huttunen P. (1997). History of forest fires in eastern Finland from the fifteenth century AD –the possible effects of slash-and-burn cultivation The Holocene 7(2): 223–228 http://dx.doi.org/10.1177/095968369700700210.

Lehtonen H. (1998). Fire history recorded on pine trunks and stumps: Influence of land use and fires on forest structure in North Karelia. Scandinavian Journal of Forest Research 13 (1–4): 462–468. http://dx.doi.org/10.1080/02827589809383007.

Lindblad M., Brunet J., Hannon G., Niklasson M., Eliasson P., Eriksson G., Ekstrand A. (2007). Forest History as a Basis for Ecosystem Restoration — A Multidisciplinary Case Study in a South Swedish Temperate Landscape. Restoration Ecology 15(2): 284–295. http://dx.doi.org/10.1111/j.1526-100X.2007.00211.x.

Ligi H. (1963). Põllumajanduslik maakasutus Eestis XVI–XVII sajandil [Agricultural land use in Estonia in XVI–XVII century]. Tallinn. 137 p. [In Estonian].

Ludemann T. (2003). Large-scale reconstruction of ancient forest vegetation by anthracology – a contribution from the Black Forest. Phytocoenologia 33(4): 645–666. http://dx.doi.org/10.1127/0340-269X/2003/0033-0645.

Lynch J.A., Clark J.C., Stocks B.J. (2004). Charcoal production, dispersal, and deposition from the Fort Providence experimental fire: interpreting fire regimes from charcoal records in boreal forests. Canadian Journal of Forest Research 34: 1642–1656. http://dx.doi.org/10.1139/X04-071.

Maaranen P. (2002). Human touch, natural processes: The development of the rural cultural landscape in southern Finland from past to present. Fennia 180(1–2): 99–109. https://fennia.journal.fi/article/view/3769. [Cited 19 Jan 2018].

Major J., Lehmann J., Rondon M., Goodale C. (2010). Fate of soil-applied black carbon: downward migration, leaching and soil respiration. Global Change Biology 16: 1366–1379. http://dx.doi.org/10.1111/j.1365-2486.2009.02044.x.

Meikar T., Uri V. (2000). Võsamaade majandamisest Eestis. Eesti metsad ja metsandus aastatuhande vahetusel [Of the management of bushland in Estonia]. In: Meikar T., Etverk I. (eds.) Akadeemilise Metsaseltsi Toimetised, vol. XI. Tartu, p. 103–120. [In Estonian].

Nguyen B.T., Lehmann J. (2009). Black carbon decomposition under varying water regimes. Organic Geochemistry 40: 846–853. http://dx.doi.org/10.1016/j.orggeochem.2009.05.004.

Nichols G.J., Cripps J.A., Collinson M.E., Scott A.C. (2000). Experiments in waterlogging and sedimentology of charcoal: results and implications. Palaeogeography, palaeoclimatology, Palaeoecology 164: 43–56. http://dx.doi.org/10.1016/S0031-0182(00)00174-7.

Niklasson M., Granström A. (2000). Numbers and size of fires: Long term spatially explicit fire history in a Swedish boreal landscape. Ecology 81: 1484–1499. http://dx.doi.org/10.1890/0012-9658(2000)081[1484:NASOFL]2.0.CO;2.

Ohlson M., Tryterud E. (2000). Interpretation of the charcoal record in forest soils: forest fires and their production and deposition of macroscopic charcoal. The Holocene 10(4): 519–525. http://dx.doi.org/10.1191/095968300667442551.

Ohlson M., Dahlberg B., Økland T., Brown K.J., Halvorsen R. (2009). The charcoal carbon pool in boreal forest soils. Nature Geoscience 2(10): 692–695. http://dx.doi.org/10.1038/ngeo617.

Patterson W.A., Edwards K.J., Maguire D.J. (1987). Microscopic charcoal as a fossil indicator of fire. Quaternary Science Review 6(1): 3–23. http://dx.doi.org/10.1016/0277-3791(87)90012-6.

Pärdi H. (1998). Talumajandus [Farm management]. In: Viires A., Vunder E. (eds.) Eesti rahvakultuur [Estonian National Culture]. Eesti Entsüklopeediakirjastus, Tallinn. p. 73−120. [In Estonian].

Poska A., Väli V., Kama P., Tomson P., Vassiljev J., Kihno K. (2017). Karula kõrgustiku taimkatte ning inimasustuse pärastjääaegne areng [Development of Vegetation and settlement after the Ice Age in Karula Upland] In: Järvet A. (ed.) Eesti Geograafia Seltsi aastaraamat. Vali Press OÜ, Tallinn. p. 25−43. [In Estonian].

Pluchon N., Vincent A.G., Gundale M.J., Nilsson M-C., Kardol P., Wardle D.A. (2016). The impact of charcoal and soil mixtures on decomposition and soil microbial communities in boreal forest. Applied Soil Ecology 99: 40–50. http://dx.doi.org/10.1016/j.apsoil.2015.11.020.

Ponomarenko E., Anderson D.W. (2013). Signature of forest fires in prairie soils. In: Damblon F. (ed.) Charcoal and microcharcoal. Continental records. Acts of the 4th International Meeting of Anthracology. Proceedings of the 4th International Meeting of Anthracology. BAR International Series 2486. Archaeopress, Oxford. p. 195–202.

Ponomarenko E., Crossland D., Loo J. (2013). Reconstructing tree species composition at the time of land clearance: two approaches compared. In: Damblon F. (ed.) Charcoal and microcharcoal. Continental records. Acts of the 4th International Meeting of Anthracology. Proceedings of the 4th International Meeting of Anthracology. BAR International Series 2486: Archaeopress, Oxford. p. 203–214.

Ponomarenko E., Ershova E., Tomson P., Bakumenko V.A. (2018). Multi-proxy analysis of sandy soils in historical slash-and-burn sites: Karula case study. Quaternary International: In Press.

Robin V., Nelle O. (2014). Contribution to the reconstruction of central European fire history, based on the soil charcoal analysis of study sites in northern and central Germany. Vegetation History and Archaeobotany 23 (Suppl 1): S51–S65. http://dx.doi.org/10.1007/s00334-014-0438-2.

Robin V., Bork H-R., Nadeau, M-J., Nelle O. (2014). Fire and forest history of central European low mountain forest sites based on soil charcoal analysis: The case of the eastern Harz. The Holocene 2(1): 35–47. http://dx.doi.org/10.1177/0959683613515727.

Rolsdat J., Blanck Y., Storaunet K.O. (2017). Fire history in a western Fennoscandian boreal forest as influenced by human land use and climate. Ecological Monographs 87(2): 219–245. http://dx.doi.org/10.1002/ecm.1244.

Rosengren M. (2000). Is it possible to detect fire history by dating charcoal in humus? Thesis, dissertation Umeå: Sveriges lantbruksuniv SLU. http://ex-epsilon.slu.se/id/eprint/470. [Cited 19 Jan 2018].

Schoch W., Heller I., Schweingruber F.H., Kienast F. (2004). Wood anatomy of central European Species. Online version: www.woodanatomy.ch. [Cited 19 Jan 2018].

Scott A.C. (2010). Charcoal recognition, taphonomy and uses in palaeo-environmental analysis. Palaeogeography, Palaeoclimatology, Palaeoecology 291: 11–39. http://dx.doi.org/10.1016/j.palaeo.2009.12.012.

Sköld E., Lagerås B., Berglund B.E. (2010). Temporal cultural landscape dynamics in a marginal upland area: agricultural expansions and contractions inferred from palynological evidence at Yttra Berg, southern Sweden. Vegetation History and Archaeobotany 19: 121–136. http://dx.doi.org/10.1007/s00334-009-0234-6.

Storaunet K.O., Rolstad J., Toeneiet M., Blanck Y. (2013). Strong anthropogenic signals in historic forest fire regime: a detailed spatiotemporal case study from south-central Norway. Canadian Journal of Forest Research 43: 836–845. http://dx.doi.org/10.1139/cjfr-2012-0462.

Zackrisson O. (1977). Influence of Forest Fires on the North Swedish Boreal Forest. Oikos 29(1): 22–32. http://dx.doi.org/10.2307/3543289.

Zackrisson O., Nilsson M-C., Wardle D. (1996). Key ecological function of charcoal from wildfire in the Boreal forest. Oikos, 77: 10–19. http://dx.doi.org/10.2307/3545580.

Talon B., Payette S., Filion L., Delwaide A. (2005). Reconstruction of the long-term fire history of an old-growth deciduous forest in Southern Québec, Canada, from charred wood in mineral soils. Quaternary Research 64(1): 36–43. http://dx.doi.org/10.1016/j.yqres.2005.03.003.

Tarand A., Jaagus J., Kallis A., (2013). Eesti kliima minevikus ja tänapäeval [Estonian climate in past and present]. University of Tartu Press, Tartu. p. 632. [In Estonian].

Tarkiainen Ü. (2014). Aletamine maastikukujunduse- ja kultuuritegurina Põhja-Euroopas ja Eestis [Slash and burn cultivation as factor of landscape design and culture in Northern Europe and in Estonia]. Tuna. Ajalookultuuri ajakiri 1: 26–41. [In Estonian].

Terhivuo J. (1989). The *Lumbricidae (Oligochaeta*) of southern Finland: species assemblages, numbers, biomass and respiration. Annales Zoologici Fennici 26: 1–23. http://www.sekj.org/PDF/anzf26/anz26-001-023.pdf. [Cited 19 Jan 2018].

Tomson P., Bunce, R.G.H., Sepp K. (2015). The role of slash and burn cultivation in the formation of southern Estonian landscapes and implications for nature conservation. Landscape and Urban Planning 137: 54−63. http://dx.doi.org/10.1016/j.landurbplan.2014.12.015.

Tomson P., Bunce R.G.H., Sepp K. (2016). Historical development of forest patterns in former slash and burn sites in Southern Estonia. In: Angoletti M., Emanueli F. (eds.) Biocultural Diversity in Europe, Environmental History, vol. 5. Springer, Switzerland. p. 303−318. http://dx.doi.org/0.1007/978-3-319-26315-1_16.

Tomson P., Kaart T., Sepp K. (2018). Role of 19th-century rotational slash-and-burn cultivation in the development of boreal forests in southern Estonia and implications for forest management. Forest Ecology and Management 409(1): 845–862. http://dx.doi.org/10.1016/j.foreco.2017.12.005.

Tryterud E. (2003). Forest fire history in Norway: From fire-disturbed pine forests to fire-free spruce forests. Ecography 26: 161–171. http://dx.doi.org/10.1034/j.1600-0587.2003.02942.x.

Van Oost K., Govers G., Van Muysen W., Quine T.A. (2000). Modelling Translocation and Dispersion of Soil Constituents by Tillage on Sloping Land. Soil Science Society of America Journal 64(5):1733–1739. http://dx.doi.org/10.2136/sssaj2000.6451733x.

Wallenius T. (2011). Major decline in fires in coniferous forests – Reconstructing the phenomenon and seeking for the cause. Silva Fennica 45(1): 139–155. http://dx.doi.org/10.14214/sf.36.

Wallenius T.H., Pitkanen A. Kuuluvainen T., Pennanen J., Karttunen H. (2005). Fire history and forest age distribution of an unmanaged *Picea abies* dominated landscape. Canadian Journal of Forest Research 35:1540–1552. http://dx.doi.org/10.1139/x05-050.

Wardle D.A., Zackrisson O., Nilsson, M-C. (1998). The charcoal effect in Boreal forests: mechanisms and ecological consequences. Oecologia 115: 419–426. http://dx.doi.org/10.1007/s004420050.

Weimarck G. (1968). Ulfshult: investigations concerning the use of soil and forest in Ulfshult, parish of Örkened, during the last 250 years. Ulfshult at the 1717 and 1747 surveys by Gunhild Weimarck. C.W.K. Gleerup, Lund. 66 p.

Weyers S.L., Spokas K.A. (2011). Impact of Biochar on Earthworm Populations: A Review. Applied and Environmental Soil Science 2011: Article ID 541592, 12 p. http://dx.doi.org/10.1155/2011/541592.

Widgren M. (2010). Reading the prehistoric landscape. Ymer 130: 69–85 http://pcwww.liv.ac.uk/~easouti/methodology_application.htm. [Cited 19 Jan 2018].

Table 1. Characteristics of charcoal and of the landscape relief and soil of the sampled sites as determined form soil pits

	Variables	Unit	Abbreviation	Range of values
Charcoal characteristics	Charcoal minimal depth	cm	C_min	0-40
	Charcoal maximal depth	cm	C_max	8-93
	Charcoal minimal depth according to the to the upper border of humus layer	cm	C_hummin	-5-40
	Charcoal maximal depth according to the upper border of humus layer	cm	C_hummax	8-88
	Thickness of layer containing charcoal	cm	C_layer	0-63
	Upper border of charcoal rich layer	cm	CR_min	0-60
	Lower border of charcoal rich layer	cm	CR_max	7-70
	Thickness of charcoal rich layer	cm	CR_layer	0-25
	Upper border of charcoal rich layer according to the upper border of humus layer	cm	CR_Hummin	0-60
	Lower border of charcoal rich layer according to the upper border of humus layer		CR_Hummax	1-70
	Estimated amount of soil charcoal		C_amount	0-3
	Presence of charcoal pieces with diameter 0.1–0.2 cm		C<0.2	0-1
	Presence of charcoal pieces with diameter 0.2–1.0 cm		C_0.2-1	0-1
	Presence of charcoal pieces with diameter more than 1.0 cm		C>1	0-1
	Presence of charcoal clusters in soil		C_cluster	0-1
	Size diversity of charcoal fragments		C_divers	0-4
	Presence of sooty layer		Sooty	0-1
	Presence of charcoal below humus layer		C_↓hum	0-1
	Presence of charcoal fragments with undisturbed structure		C_<struct	0-1
Relief characteris-tics	Relief: (1) flat < (2) footslope < (3) slope < (4) top of hill		relief	1-4
	Microrelief: : (1) flat < (2) small incline < (3) incline		Micro_r	1-3
Soil characteristics	Litter thickness	cm	litter	0-8
	Humus thickness	cm	humus	0-93
	Soil texture: (1) coarse sand < (2) fine sand < (3) sandy loam < (4) light loam < (5) medium loam< (6) heavy loam < (7) glay		texture	1-7
	Soil type: (1) Podzols and Gleyic soils < (2) Haplic Albeluvisols and Deluvial soils < (3) Stagnic Luvisols < (4) Mollic Cambisols and Luvisols		soil_type	1-4
	Signs of bleaching in soil profile		bleach	0-1

Table 2. Average values of studied charcoal, relief and soil characteristics according to different land use groups, and statistical significance of between-groups differences (permutation ANOVA; p-values indicating statistically significant differences are presented in bold face).SB: slash-and-burn cultivation site.

Charcoal, relief and soil characteristics	Land use before 19th century					Land use at 19th century				Land use at 21st century				
	Arable land	Recent SB	Older SB	Forest	p-value	Arable land	SB	Forest	p-value	Open	Expri-mental SB	Forest	Recent forest fire	p-value
Charcoal minimal depth, cm	20.9	13.2	9.7	10.0	**0.003**	20.9	13.2	10.0	**<0.001**	20.9	2.0	11.7	1.5	**<0.001**
Charcoal maximal depth, cm	40.6	25.6	16.7	20.6	**0.003**	40.6	25.6	19.9	**0.002**	40.6	19.0	23.0	31.7	**0.017**
Charcoal minimal depth according to the to the upper border of humus layer, cm	20.9	8.7	2.7	5.5	**0.001**	20.9	8.7	5.0	**<0.001**	20.9	2.0	7.0	-2.8	**<0.001**
Charcoal maximal depth according to the upper border of humus layer, cm	40.6	20.8	9.7	16.1	**<0.001**	40.6	20.8	15.0	**0.001**	40.6	19.0	18.1	27.3	**0.002**
Thickness of layer containing charcoal, cm	19.8	12.3	7.0	10.6	0.144	19.8	12.3	10.0	0.099	19.8	17.0	11.2	30.2	**0.002**
Upper border of charcoal rich layer, cm	32.1	14.9	10.6	12.5	**<0.001**	32.1	14.9	12.2	**<0.001**	32.1	2.3	13.7	11.8	**<0.001**
Lower border of charcoal rich layer, cm	38.8	21.1	16.7	17.8	**<0.001**	38.8	21.1	17.6	**<0.001**	38.8	9.5	19.5	19.5	**<0.001**
Thickness of charcoal rich layer, cm	6.6	6.4	6.4	5.2	0.705	6.6	6.4	5.5	0.614	6.6	7.0	6.0	7.7	0.751
Upper border of charcoal rich layer according to the upper border of humus layer, cm	32.1	10.4	3.6	8.0	**<0.001**	32.1	10.4	7.2	**<0.001**	32.1	2.3	8.9	7.5	**<0.001**
Lower border of charcoal rich layer according to the upper border of humus layer, cm	38.8	16.6	9.7	13.2	**<0.001**	38.8	16.6	12.6	**<0.001**	38.8	9.5	14.8	15.2	**<0.001**
Estimated amount of soil charcoal (0 – 3)	1.8	1.9	2.0	1.7	0.470	1.8	1.9	1.7	0.497	1.8	2.5	1.8	2.3	0.140
Presence of charcoal pieces with	1.0	0.9	0.9	0.8	0.341	1.0	0.9	0.8	0.237	1.0	1.0	0.8	1.0	0.551

diameter 0. 1–0.2 cm														
Presence of charcoal pieces with diameter 0.2–1.0 cm	1.0	0.9	0.9	0.8	0.692	1.0	0.9	0.8	0.551	1.0	1.0	0.9	1.0	0.726
Presence of charcoal pieces with diameter more than 1.0 cm	0.4	0.5	0.3	0.4	0.607	0.4	0.5	0.4	0.383	0.4	0.8	0.4	0.5	0.672
Presence of charcoal clusters in soil	0.3	0.3	0.1	0.3	0.897	0.3	0.3	0.3	1.000	0.3	0.8	0.3	0.3	0.327
Size diversity of charcoal fragments	2.6	2.5	2.1	2.3	0.532	2.6	2.5	2.3	0.370	2.6	3.5	2.4	2.8	0.149
Presence of sooty layer	0.1	0.1	0.1	0.2	0.917	0.1	0.1	0.2	0.897	0.1	0.0	0.1	0.3	0.375
Presence of charcoal below humus layer	0.5	0.5	0.4	0.6	0.818	0.5	0.5	0.6	0.865	0.5	0.5	0.6	1.0	0.153
Presence of charcoal fragments with undisturbed structure	0.3	0.4	0.4	0.3	0.362	0.3	0.4	0.3	0.332	0.3	1.0	0.4	0.7	**0.033**
Relief:	2.8	2.8	2.6	2.4	0.544	2.8	2.8	2.4	0.391	2.8	2.3	2.6	2.5	0.920
Microrelief:	1.9	1.4	1.3	1.3	0.127	1.9	1.4	1.3	0.062	1.9	2.5	1.3	1.7	**0.003**
Litter thickness, cm	0.0	4.7	7.0	5.1	**0.001**	0.0	4.7	5.4	**<0.001**	0.0	0.0	5.0	4.3	**<0.001**
Humus thickness, cm	38.6	17.7	11.0	12.1	**<0.001**	38.6	17.7	11.9	**<0.001**	38.6	25.0	15.0	0.0	**<0.001**
Soil texture	3.0	4.2	2.4	4.8	0.163	3.0	4.2	4.4	0.528	3.0	3.0	4.3	1.0	**0.042**
Soil type	2.5	2.6	2.7	2.3	0.423	2.5	2.6	2.4	0.554	2.5	2.3	2.5	1.0	**0.003**
Signs of bleaching in soil profile	0.0	0.4	0.4	0.5	0.052	0.0	0.4	0.5	0.026	0.0	0.0	0.5	1.0	**<0.001**

817 SB – slash and burn site, Open – open vegetation (former arable field covered by grasslands), Exp. SB – experimental SB, FF – forest fire site

Table 3. Average values of charcoal, relief and soil characteristics in hilltops and footslopes, and statistical significance of the difference (permutation test for dependent samples; significant p-values are in bold face).

Characteristics	Top	Footslope	p-value
Charcoal minimal depth, cm	12.2	14.0	0.905
Charcoal maximal depth, cm	26.9	43.6	0.067
Thickness of layer consisting charcoal, cm	14.7	29.6	0.033
Upper border of charcoal rich layer, cm	14.9	25.3	0.053
Lower border of charcoal rich layer, cm	20.3	31.9	0.066
Thickness of charcoal rich layer, cm	5.36	6.58	0.301
Estimated amount of soil charcoal	1.33	2.17	**0.013**
Presence of charcoal pieces with diameter 0. 1–0.2 cm	0.75	1.00	0.157
Presence of charcoal pieces with diameter 0.2–1.0 cm	0.75	1.00	0.157
Presence of charcoal pieces with diameter more than 1.0 cm	0.25	0.83	**0.008**
Presence of charcoal clusters in soil	0.17	0.50	**0.046**
Presence of sooty layer	0.08	0.25	0.317
Presence of charcoal fragments with undisturbed structure	0.25	0.58	**0.046**
Relief:	3.67	2.33	**0.014**
Microrelief:	1.92	1.83	0.706
Litter thickness, cm	3.08	3.75	0.144
Humus thickness, cm	12.0	30.0	**0.042**
Soil texture	2.25	2.67	0.096
Soil type:	2.25	1.83	0.059
Signs of bleaching in soil profile	0.42	0.42	1.000

Table 4. The average depth of charcoal pieces and distribution by tree species depending on the land use in 19th and 21st century. The results are presented for all excavations and for trenches and pits separately. The p-values present the statistical significance of land use groups' differences (permutation ANOVA; significant p-values in bold face).

		Average depth, cm	*Pinus*	*Picea*	*Betula*	*Alnus*	*Populus*	*Acer*	Non- RW
All excavations (355 pieces)									
	Land use at 19th century								
Arable land		42.6	20.4%	54.6%	9.5%	9.8%	0.0%	5.7%	0.0%
SB cultivation		42.2	50.3%	24.3%	8.3%	11.4%	1.0%	0.0%	4.5%
Forest		15.4	69.8%	7.7%	2.1%	3.7%	0.0%	0.0%	16.7%
	p-value	**<0.001**	**0.021**	**0.003**	0.322	0.308	0.273	0.111	0.156
	Land use at 21st century								
Open		42.57	20.4%	54.6%	9.5%	9.8%	0.0%	5.7%	0.0%
Forest		26.9	61.4%	14.8%	4.8%	7.0%	0.4%	0.0%	11.5%
	p-value	0.137	0.006	0.007	0.646	0.744	1	0.12	0.275
Pits (185 pieces)									
	Land use at 19th century								
Arable land		42.6	20.4%	54.6%	9.5%	9.8%	0.0%	5.7%	0.0%
SB cultivation		32.0	52.0%	20.5%	8.8%	17.5%	1.3%	0.0%	0.0%
Forest		14.7	75.8%	7.1%	2.5%	4.3%	0.0%	0.0%	10.3%
	p-value	**<0.001**	**0.005**	**0.021**	0.649	0.294	0.490	0.193	0.303
	Land use at 21st century								
Open		42.6	20.4%	54.6%	9.5%	9.8%	0.0%	5.7%	0.0%
Forest		20.1	68.3%	11.3%	4.5%	8.5%	0.4%	0.0%	7.1%
	p-value	0.006	**0.004**	**0.003**	0.810	0.880	1	0.162	0.787
Trenches (170 pieces)									
	Land use at 19th century								

SB cultivation	53.5	48.4%	28.6%	7.7%	4.7%	0.7%	0.0%	9.5%
Forest	19.6	33.8%	11.1%	0.0%	0.0%	0.0%	0.0%	55.1%
p-value	0.134	0.456	0.214	0.336	0.338	1	NA	**0.038**
Land use at 21st century								
Forest	43.8	44.2%	23.6%	5.5%	3.3%	0.5%	0.0%	22.5%

SB – slash and burn, Open – open vegetation (former arable field covered by grasslands);
Non-RW – charcoal not of round wood origin

Table 5. Spearman correlations between charcoal, and relief and soil characteristics; statistically significant ($p<0.05$) correlation coefficients are presented in bold face

Charcoal characteristics	Relief characteristics.		Soil characteristics				
	Relief	Micro-relief	Litter thickness	Humus thickness	Soil texture	Soil type	Bleaching
Charcoal minimal depth, cm	0.19	-0. 02	-0.07	**0.55**	0.09	**0.30**	**-0.31**
Charcoal maximal depth, cm	-0.02	0.19	**-0.20**	**0.58**	**-0.22**	**-0.23**	-0.11
Charcoal minimal depth according to the to the upper border of humus layer, cm	0.16	0.06	**-0.42**	**0.63**	0.04	**0.33**	**-0.43**
Charcoal maximal depth according to the upper border of humus layer, cm	-0.01	0.22	**-0.39**	**0.63**	**-0.22**	-0.18	-0.19
Thickness of layer containing charcoal, cm	-0.13	**0.22**	-0.19	**0.33**	**-0.30**	**-0.43**	0.06
Upper border of charcoal rich layer, cm	-0.12	0.04	**-0.20**	**0.62**	0.00	0.11	**-0.32**
Lower border of charcoal rich layer, cm	-0.13	0.16	**-0.23**	**0.57**	-0.06	0.01	**-0.25**
Thickness of charcoal rich layer, cm	-0.05	**0.24**	-0.08	0.00	-0.09	-0.18	0.19
Charcoal rich layer according to the upper border of humus to layer, cm	-0.12	0.10	**-0.46**	**0.66**	-0.04	0.15	**-0.40**
Charcoal rich layer according to the upper border of humus to layer, cm	-0.13	0.20	**-0.46**	**0.62**	-0.08	0.05	**-0.33**
Estimated amount of soil	-0.09	0.16	0.00	0.07	0.09	**-0.25**	0.17

charcoal							
Presence of charcoal pieces with diameter 0. 1–0.2 cm	-0.02	0.11	-0.03	0.02	0.05	**-0.29**	0.14
Presence of charcoal pieces with diameter 0.2–1.0 cm	-0.10	**0.20**	-0.16	0.10	-0.13	**-0.20**	-0.02
Presence of charcoal pieces with diameter more than 1.0 cm	0.02	0.17	0.05	0.15	0.12	**-0.22**	0.07
Presence of charcoal clusters in soil	0.00	0.12	-0.12	0.08	0.05	-0.12	0.11
Size diversity of charcoal fragments	-0.03	**0.24**	-0.09	0.15	0.05	**-0.33**	0.13
Presence of sooty layer	**-0.22**	-0.09	0.05	0.14	-0.17	**-0.33**	**0.22**
Presence of charcoal below humus layer	-0.01	0.03	0.00	**-0.21**	-0.15	**-0.31**	0.18
Presence of charcoal fragments with undisturbed structure	0.09	0.16	0.01	0.07	0.07	-0.20	0.08

Site	Excavat. type	Land use in 19th century	Depth, cm	Character of charcoal	Soil layer	Soil type in site	Dating method	Date BP	Calibrated AD (probability 95.4%) from	to	Weighted average calAD	Error of weighted average calAD	Nearest historical settle-ment	Period of settlement	Distance of excavation from settlement, km
Karsi	trench	SB	14	dispersed	humus	sand, Haplic Albeluvisol	AMS	160±30	1664	...	1796	85	Ähijärve	RIA; LIA	1,2
Karsi			52	dispersed layer	transitional from humus to eluvial		con	1278±55	655	879	747	62			
Koobassaare	trench	SB	20	dispersed	humus	sand Haplic Albeluvisol	AMS	180±35	1652	...	1788	89	Apja	LIA	1,5
			60–80	single pieces	illuvial		con	923±55	1017	1221	1112	57			
Ahero	trench	SB	16–0	dispersed	humus	sand Haplic Albeluvisol	con	211±55	1522	...	1755	111	Alakonnu	MA	0,6
Ahero			40–45	dispersed layer	transitional from humus to eluvial		AMS	3730±35	-2276	-2028	-2126	61			
Mähkli	trench	SB	20–37	dispersed	humus	sand Podzol	AMS	315±30	1484	1648	1566	47	Mähkli	PreRIA; RI; LIA; MA	0,9
			40–60	dispersed	humus		con	316±65	1442	...	1575	86			
	trench		75–110	dispersed layer	mixed transitional		con	1050±50	881	1151	980	59			
			130–165	sparsed and small clusters	eluvial		con	3861±50	-2471	-2155	-2336	82			
Kautsitee	trench	forest	10–15	dispersed	eluvial	sand Podzol	AMS	810±30	1169	1270	1228	27	Ähijärve	RIA; LIA; MA	3,3
		forest	15–30	single small	transitional from eluvial to illuvial		AMS	1505±30	431	635	554	47			
Pehme	trench	forest	4–17	dispersed layer	eluvial	sand Podsol	con	250±50	1483	...	1672	119	Ähijärve	RIA.;LIA.; MA	1,6
		forest	30–40	single	illuvial		AMS	4510±40	-3361	-3090	-3216	83			
Koobassaare	pit	SB	0–18	dispersed	humus	sand, Haplic Albeluvisol	AMS	95±30	1682	...	1789	89	Apja	LIA	1,5
			18–35	single	illuvial		AMS	925±30	1026	1182	1101	42			
Alakonnu	pit	SB	7–20	dispersed	humus	sand, Haplic Albeluvisol	AMS	140±30	1669	1945	1805	82	Alakonnu	MA	0,2
			20–50	dispersed	illuvial		AMS	185±30	1650	...	1786	90			
Rabasaar	pit	forest	20–30	dispersed and dispersed layer	mixed eluvial	sand, Podzol	con	297±50	1464	1796	1582	77	Kolski	MA; EMA	0,8
Kallete 4	pit	forest	33	cluster	illuvial	sand Podzol	con	4940±50	-3913	-3639	-3731	63	Mähkli	PreRIA; RI; LIA; MA	1,7

Table 6. The dates of soil charcoal sample

Dates that are coloured red are out of range. PreRIAR–Pre-Roman Iron Age (500 BC–50 AD); RIA–Roman Iron Age (50–450 AD); LIA–Late Iron Age (550–1200 AD); MA–Middle Ages (1200–1550 AD); EMA–Early Modern Age (1550–1800 AD) SB–slash and burn cultivation site in the 19th century, forest–forest in 19th century; AMS–accelerator mass spectrometry radiocarbon dating, con- conventional radiocarbon dating

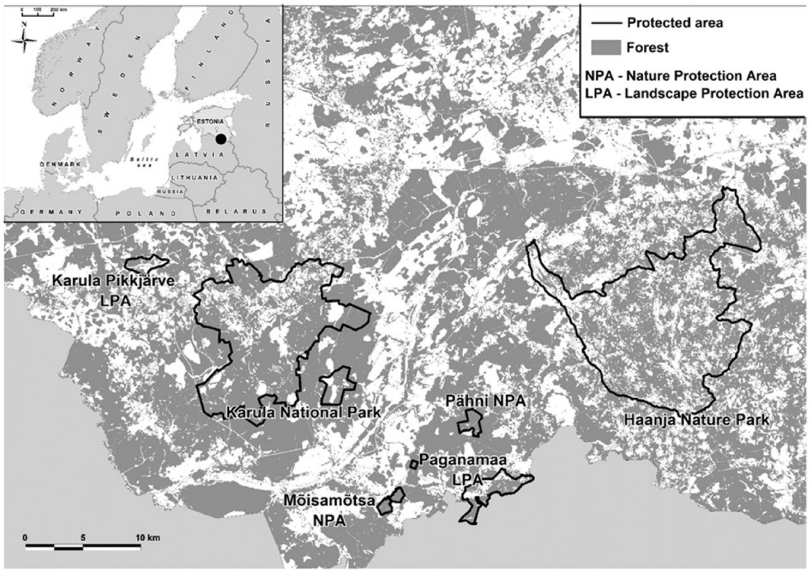

Figure1. Areas within which study sites were located.

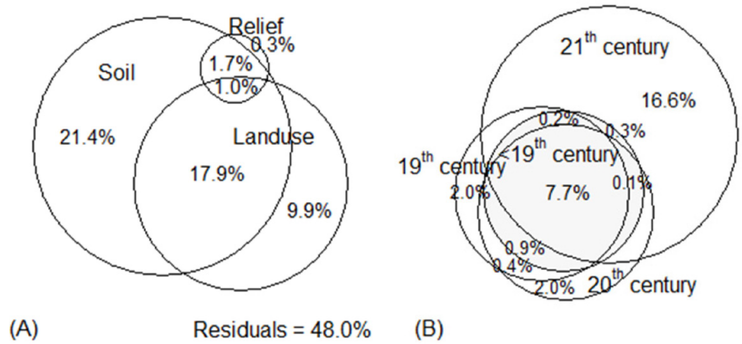

Figure 2. Results of variance partitioning analysis fitted with Euler diagram. (A) The proportion of charcoal characteristics variation accounted for by soil parameters, relief and land-use, and their intersections; (B) the proportion of charcoal characteristics variation explained only by land-use divided into parts according to the land-use periods. The graphical fit in figure (B) is not ideal but proportionally correct: the root mean square error of fitted proportions is 0.5%.

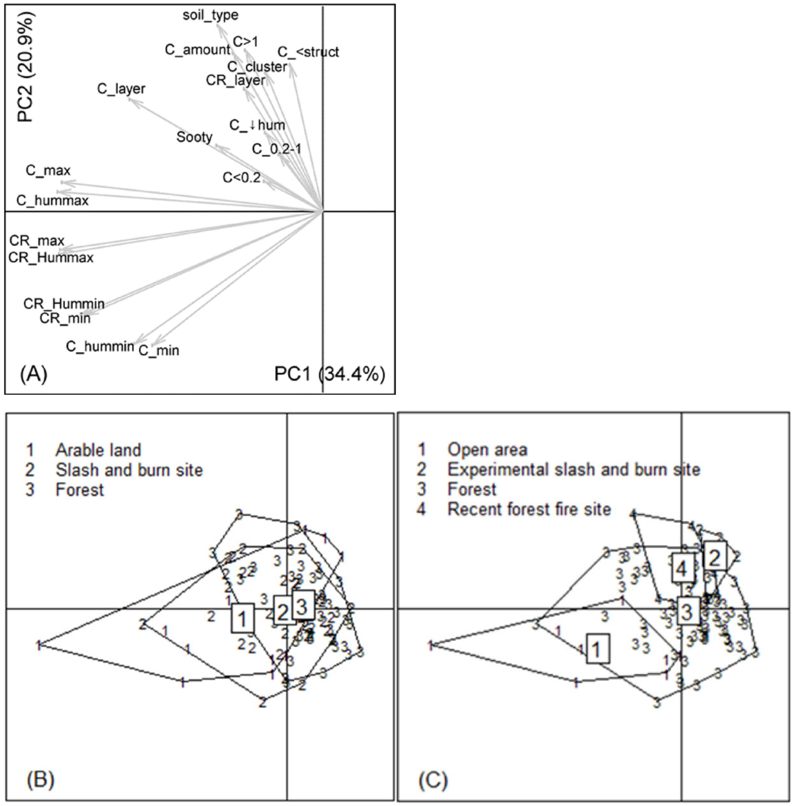

Figure 3. Principal component (PC) analysis of charcoal characteristics: (A) lengths and directions of arrows denote the weights of charcoal characteristics concerning the first two principal components; (B) and (C) location of study sites on the plane of the first two principal components, each site is marked with number according to the land use in 19th and 21st century, respectively, and centroids of different groups are denoted with the numbers in larger font in boxes.

Figure 4. Trench in field bank in former slash and burn site in Karsi. Photo by Pikne Kama.

Figure 5. Trench in forest site Kautsitee. Photo by Pille Tomson.

Appendix 1

	Mapped area	Title of map	Drawn	Scale	Reference code of Estonian National Archive	Protected Area
1	Vana-Antsla manor	Charte von dem privaten Gute Alt-Anzen	1871-72	1:20800	EAA.3724.4.1838	Karula
2	Boose manor	Charte von dem privaten Gute Bosenhof	1871-72	1:18081	EAA.3724.4.1867	Karula
3	Karula manor	Situations Charte von dem Gute Carolen	1867	1:20800	EAA.3724.5.2803	Karula
5	Vana-Roosa manor	Charte von den Hofsländereien des privaten Gutes Rosenhof	1886	1:9245	EAA.3724.4.1914 . 1	Pähni
6	Krabi manor	General Charte von dem im Livländischen Gouvernement , Werroschen Kreise, Raugeschen Kirchspiele belegenen privaten Gute Schönangern.	1887	1:52000	EAA.2469.1.769	Paganamaa
7	Map of six farms	Charte des zu dem Privatgute Rosenhof gehörigen Grundstücks Waldeshöh oder die Gesinden Alska, Orrando, Surepeter Jaan, Gusta, Adam und die Buschw. Jaenesse.	1876	not presented	EAA.2072.5.643. 1	Paganamaa

8	Farm map	Charte des zu dem Privatgute Rosenhof gehörigen Gesindes Wastne Sockari Nr.37.	1874	1:52000	EAA.2486.3.276.63	Paganamaa
9	Farm map	Charte des zu dem Privatgute Rosenhof gehörigen Gesindes Tagga Kerrekutzi Nr.39	1874	1:52000	EAA.2486.3.276.39	Paganamaa
10	Map of Hargla parish	Kirchspiel Hargel. Kreis Werro.	1900	1:42 000	EAA.3724.5.2822.1	Mõisamõtsa

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2012–...	Estonian University of Life Sciences, Institute of Agricultural and Environmental Sciences, researcher, senior specialist
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1993–1994	Antsla Municipality, advisor
1984–1993	Work in home farm

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Main publications

2018

Tomson, P., Kaart, T., Sepp, K. (2018). Role of 19th-century rotational slash-and-burn cultivation in the formation of boreal forest vegetation and implications for management. Forest Ecology and Management, 409, 845−862.10.1016/j.foreco.2017.12.005.

Poska, A., Väli, V., Tomson, P., Vassiljev, J., Kihno, K., Alliksaar, T., Villoslada, M., Saarse, L., Sepp, K. (2018). Reading past landscapes: combining modern and historical records, maps, pollen-based vegetation reconstructions, and the socioeconomic background. Landscape Ecology, 33, 529−546.10.1007/s10980-018-0615-2.

2016

Tomson, P., Bunce, R.G.H., Sepp, K. (2016). Historical Development of Forest Patterns in Former Slash and Burn Sites in Southern Estonia. In: Angoletti, M., Emanueli, F. (Ed.). Biocultural Diversity in Europe (303−318). Switzerland: Springer. (Environmental History; 5).10.1007/978-3-319-26315-1_16.

2015

Tomson, P.,; Bunce, R.G.H., Sepp, K. (2015). The role of slash and burn cultivation in the formation of southern Estonian landscapes and implications for nature conservation. Landscape and Urban Planning, 137, 54−63.10.1016/j.landurbplan.2014.12.015.

2010

Jääts, L., Kihno, K., Tomson, P., Konsa, M.(2010). Tracing fire cultivation in Estonia. Metsanduslikud uurimused (Forestry Studies), 53, 53−65. DOI:10.2478/v10132-011-0089-3.

Conference abstracts

Jääts, L., Konsa, M., Kihno, K., Tomson, P. "Slash-and-burn land-use in Estonian agrarian landscapes". 24th session of the PECSRL biennial international conference „Living in Landscapes: Knowledge, Practice, Imagination", Riga and Liepaja, 23–27 August 2010.

Jääts, L., Tomson, P., Kihno, K.. Konsa, M. "Bushland management and its development in the late 19th - 20th centuries in southern Estonia". 6th ESEH Conference „Encounters of Sea and Land", Turku, 28 June–2 July 2011.

Tomson, P. "Changing slash-and-burn landscapes in South Estonia". 3rd International Schöntal Conference "Farming in the Forest. Ecology and Economy of Fire in Prehistoric Agriculture", Kloster Schöntal, 11–15 July 2012.

Tomson, P., Bunce, R.G.H., Sepp, K. „ The Impact of Fire Cultivation on the Development in the South-Estonian landscapes" „IALE 2013 European Congress. "Changing European Landscapes", Manchester, 9–12 September 2013.

Tomson, P., Sepp, K., Bunce, R.G.H. „Historical development of slash and burn forest patterns in South Estonia". Conference „Linking Biological and Cultural Diversity in Europe". Firenze, 8–11 April 2014.

Tomson, P., Sepp, K. "Ash and shit. The forces behind disappearance of the fire cultivation landscapes in South Estonia". 26th session of the PECSRL biennial international conference: „Unraveling the Logics of Landscape", Gothenburg and Mariestad, 8–12. September 2014.

Tomson, P., Bunce, R.G.H. "An example of the application of the methods in landscape history –a case study from Southern Estonia".

17th International Symposium on Landscape and Landscape Ecology, Nitra, 27–29. May 2015.

Tomson, P., Bunce, R.G.H. "The extent and impacts of slash and burn cultivation in Northern Europe. A case study from Karula and Haanja uplands", The 6th Nordic Geographers Meeting Geographical Imagination: Interpretations of Nature, Art and Politics", Tallinn and Tartu, 15–19 June. 2015.

Tomson, P., Bunce, R.G.H. "Legacies of slash and burn cultivation – an integrated study of landscape pattern and forest vegetation in Southern Estonia". 9th IALE World Congress, Portland, 5–10 July 2015.

Tomson, P., Bunce, R.G.H., Sepp, K. "The contribution of former slash and burn fields to forest biodiversity", IUFRO Landscape Ecology Conference "Sustaining ecosystem services in forest landscapes", Tartu, 23–30 August 2015.

Tomson, P., Sepp, K. „Methods exploring the slash and burn landscapes history in Estonian uplands"„The 27th session of the PECSRL biennial international conference – „Mountains, uplands, lowlands. European landscapes from an altitudinal perspective", Innsbruck and Seefeld, 05–09 September 2016.

Tomson, P., Sepp, K. "Forest soil charcoal as an indicator of historical land use. Case study from Southern Estonia". 9th ESEH Conference "Natures in between. Environments in areas of contact among states, economic systems, cultures and religions", Zagreb, 28 June–02 July 2017.

Tomson, P., Sepp, K. "Soil charcoal as indicator of slash and burn cultivation". EAA Annual conference "Building the bridges", 30 August–3 September 2017.

Tomson, P., Sepp, K. "Using 19th century land use maps to study forest vegetation of former rotational slash and burn sites". IALE European Congress, Ghent, 12–15 September 2017.

Tomson, P., Sepp, K. "Wildfires and slash and burn cultivation as sources of forest soil charcoal". North American Forest Soils Conference, Quebec, 10–16 June 2018.

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Teenistuskäik:

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INVASIVE NON-INDIGENOUS CRAYFISH SPECIES AS A THREAT TO THE NOBLE CRAYFISH (*ASTACUS ASTACUS* L.) POPULATIONS IN ESTONIA
INVASIIVSED VÄHI VÕÕRLIIGID JA NENDE OHUSTAV MÕJU JÕEVÄHI (*ASTACUS ASTACUS* L.) ASURKONDADELE EESTIS
Emeriitprofessor Tiit Paaver, professor Riho Gross
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